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Wind Turbine Data Acquisition and Analysis System

Bernard Stiefeld

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ABSTRACT

Under Department of Energy (DOE) sponsorship, Sandia Laboratories has implemented a program to develop vertical-axis wind turbine (VAWT) systems. One aspect of this program has been the development of an instrumented test site adjacent to Sandia Laboratories' Technical Area I on Kirtland Air Force Base. Three VAWTs are now in operation on this test site. This paper describes the data acquisition and analyses system developed to meet the needs of the VAWT test site. The system employs a 16-bit work-length minicomputer as the major element in a stand-alone configuration. A variety of peripheral devices perform the required data acquisition functions and provide for data display and analysis. Included is a disk-based software operating system that supports a mass storage-file system, high-level language, and auxiliary software procedures.

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WIND TURBINE DATA ACQUISITION AND ANALYSIS SYSTEM

Introduction

Objectives

The objective of this program was to develop an instrumented outdoor wind laboratory to evaluate various aspects of wind turbine performance and support general site-oriented wind studies. Instrumentation and supporting software developed for this laboratory can be applied to the evaluation of any type wind turbine or various other devices that may or may not be related to the wind program. The specific purpose of this outdoor laboratory and its instrumentation, however, is to evaluate VAWT prototype units developed as part of Sandia's wind-energy program.

VAWT Characteristics and a General Background of Wind-Power Studies

Descriptions of VAWT characteristics and a general background on the subject of wind power can be obtained by reviewing References 1, 2, and 3. At Sandia, we have erected three wind turbines: 2-m, 5-m, and 17-m machines. The 17-m machine has been outfitted with the greatest number of transducers, and its instrumentation is described in some detail.

In evaluating the performance of the 17-m VAWT, we have concentrated on two areas:

1. Structural aspects of turbine operation, primarily blade performance, including vibratory response characteristics.[4, 5]
2. Performance characteristics of torque output vs wind velocity and related studies of system power losses and electrical output characteristics.[6, 7]

Major factors considered in wind studies are determination of wind-velocity history, gust-related frequency parameters, and terrain-related wind-shear factors. (Wind shear is evidenced by velocity difference with altitude of ~ 0 to 45 m [0 to 150 ft] above the surface.) This factor is important in evaluating turbine efficiency as it is applied to find the wind velocity at the turbine equator. It should be noted that the power available in a moving fluid stream is proportional to the cube of the velocity; an accurate determination of wind velocity is therefore needed for calculation of performance factors.

Criteria for Design of a Wind-Turbine Data Acquisition and Analysis System for Sandia

In designing a data acquisition system, consideration is usually given to traditional physical parameters such as number of channels, required sampling rates, voltage levels, noise sources, etc. However, in developing a system for use in the laboratory environment that exists at Sandia, consideration should be given to other more subtle factors. Among these are

1. background and training of principal users of the system,
2. desired end use of the data,
3. desired or required speed of data analysis wanted and complexity of analysis,
4. propensity to modify system requirements for either hardware or software.

The ultimate usefulness and longevity of a laboratory-located system may depend as much on proper evaluation of these four considerations as on any traditional factors. In this instance, the users of the equipment and data were essentially the same group of Sandia staff members, all highly trained and intimately involved with both operational and analytic phases of the Sandia wind-energy program. Many of these staff members are well versed in use of FORTRAN and time-share terminal operations, but none are familiar with detailed computer operations, and none have training at the assembly-language level. Discussions with these staff members indicated strong requirements for a flexible software and hardware system. The staff agreed that initial operational data acquisition should use the "method of BINS"[6, 7] (a summary of "method of BINS" is contained in Reference 7), but much uncertainty existed about probable future testing after the initial evaluations. A capability for general wind characteristic studies was also desired.

Blade and cable tiedown systems for dynamic and steady-state conditions[4, 5] were analyzed. Based on data from studies, we made decisions about sampling rates, blade strain-gage locations, and transducer/voltage response.

For technical personnel trained in their own specialties but with little experience in assembly language, computer programming, and interfacing instruments, the hardware/software problems can be formidable. To overcome this hurdle, the following four guides were established for procuring the control system and related instrumentation:

1. To facilitate software development and future software expansion, the system will support a high-level language, preferably one generally familiar to Sandia Laboratories personnel. An adequate file system will be available for program storage, modification, and data manipulations. The key element here is the use of a well-known, high-level language.

2. A fast multichannel analog-to-digital (A/D) converter will be the main data-acquisition unit. As a corollary to this decision, transducers and signal conditioning modules will be procured that will provide analog outputs proportional to the input stimulus. The rationale here is that the A/D converter input lines will be brought out of the computer system to a plug connector or strip connection system. Interfacing then involves simply wiring the analog outputs to the A/D input plugs. Additions or modifications are straightforward and generally would require no modifications to the computer input-output (I/O) system. A new transducer could thus be added by personnel with little detailed computer hardware background. For software, a general-purpose A/D call from the high-level language is used so that no assembly language programming effort is required if a new transducer is added to the system.

3. To assure the quality of the data acquired and to speed up data review, the system should be capable of performing real or near real-time data reduction and display. The term "display" here includes a reasonable graphic capability as contrasted to a minimal printing capability.

4. All elements of the computer system should come from one company, one having a good service reputation in the Albuquerque area. This requirement minimizes confusion in pinpointing responsibility when difficulties arise. Dealing with several companies to put a complex system together is almost impossible if technical problems arise.

The major trade-off for these four items is cost. Procurement time is probably reduced because of simplifications from the user's view. Use of a high-level language generally implies supporting software items such as an editor, compiler or interpreter, file management, etc. Convenience and ease of use increases disk speed and capacity requirements, and therefore the cost of the disk system increases over the cost of a minimal assembly-language-based system. The cost of a suitable A/D converter will be greater than that for a minimal system and additional memory to handle files and more complex data reduction programs will be required. Finally, the I/O devices to support graphic output on a fast near real-time basis will cost much more than a simple TTY device or modest speed-line printer device.

Summary

Delivery of hardware elements of the system was made in September through November of 1976. The data system was operational at the VAWT site in January 1977, acquiring data from the 15-m VAWT that was in place. The 17-m VAWT was installed in February and March 1977, with initial testing starting in March. The 2-m machine came into operation in March 1978.

All three machines have been interfaced with the data system with little or no deviation from the original planning. The entire system has exhibited a satisfactory level of reliability with no downtime exceeding 3 days. In approximately 18 months the data system has been down only twice. Strain-gage connections have been the principal hardware problem. Three strain gages out of 21 are now inoperable due to open leads.

Much FORTRAN-based software has now been written for the system. Generally, individual staff members have written their own programs, with at least four staff members having become proficient on the system. Several general wind analysis procedures have been placed on the system, taking advantage of the ease of programming and anemometer interfacing. The graphic capability of the system has been used extensively. This has resulted in not utilizing the magnetic tape system as intended to transfer data to the Sandia central computer system.

At this time, the only significant change to the system planned is the addition of a cassette reader. This reader will read tapes from remote weather stations. Software will be developed to reduce this data to evaluate long-term site wind characteristics.

System Hardware Description

Significant elements of the data acquisition and control system are diagrammed in Figure 1. The system Central Processing Unit (CPU), an HP 21 MX minicomputer 16-bit machine with 32, 767 words of core memory, was chosen to meet the four criteria outlined in the previous section. Sandia's facility and digital system design and development had acquired considerable software and hardware experience on a recently installed digital acquisition system.[8, 9] A suitable local service organization was available, and several hardware/software requirements were similar to those for the proposed wind test facility and the recently completed centrifuge digital acquisition and analysis system.

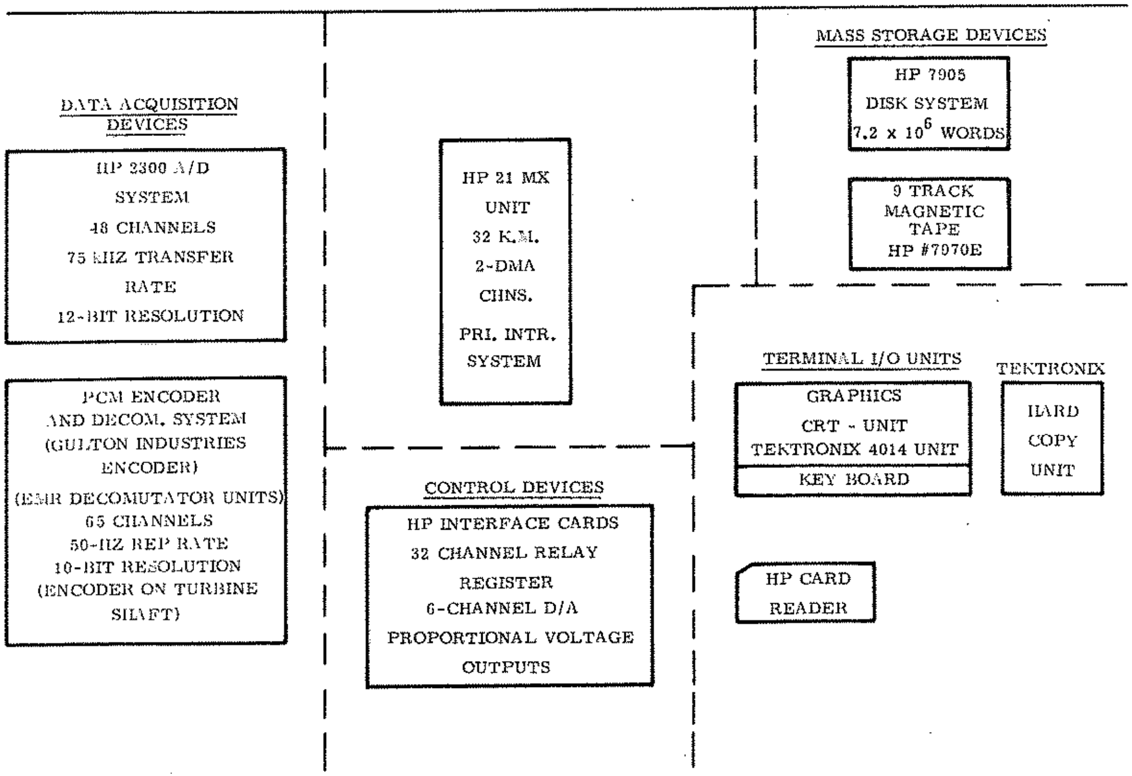

Figure 1. HP 21 MX Computer System Elements

For ease of interfacing and system software utilization, the following items were sole-sourced from the CPU manufacturer at the same time the CPU order was placed.

1. HP 2313 A/D system with 48 channels
2. HP multiprogrammer unit
3. HP 7905 7.2 megaword disk system
4. HP 7970E 9-track high-density magnetic tape system
5. HP relay interface card
6. HP paper tape reader
7. HP card reader

All equipment is mounted in a standard 6-ft tall, double-bay instrument rack. Items 3, 4, 6, and 7 above deal only with the CPU unit. Their service maintenance is a problem for the HP service organization. Items 1, 2, and 5 deal with data signals from the turbines, but it is easy to determine if the turbine signals are present and, if so, whether malfunctions are HP service problems. It is important that the wind group's few instrument people do not spend excessive time dealing with the complex CPU/peripheral interfaces. After initial shakedown, this equipment has been reliable, with little down time. The Tektronix graphics terminal and its hard-copy unit were procured because of relative simplicity in use, availability of software support at Sandia, and lack of competitive options during procurement.

The following information describes specifications for the significant system components.

Pulse Code Modulator (PCM) Encoder, Bit Synchronizer, Decommutator and Interface

The major task of the PCM system is to provide a noise-free way to acquire high- and low-level data from the rotating members of the turbine. Figure 2 is a system diagram of the encoder system. Basically, the encoder takes multiple analog data channels and converts from analog form to a serial digital data stream, adding frame-sequence and word-sequence coding. The bit synchronizer and decommutator located in Building 899 near the CPU decode the serial stream, provide frame pulses, and parallel digital data words to the computer interface unit for acquisition by the computer as determined by appropriate programs. The advantage of the PCM system is that multiple channels (65 in our case) of data are compressed into a single transmission channel containing high-level digital data. This high-level digital stream is largely immune to the usual analog AM noise encountered in slip-ring operation and cable transmission.

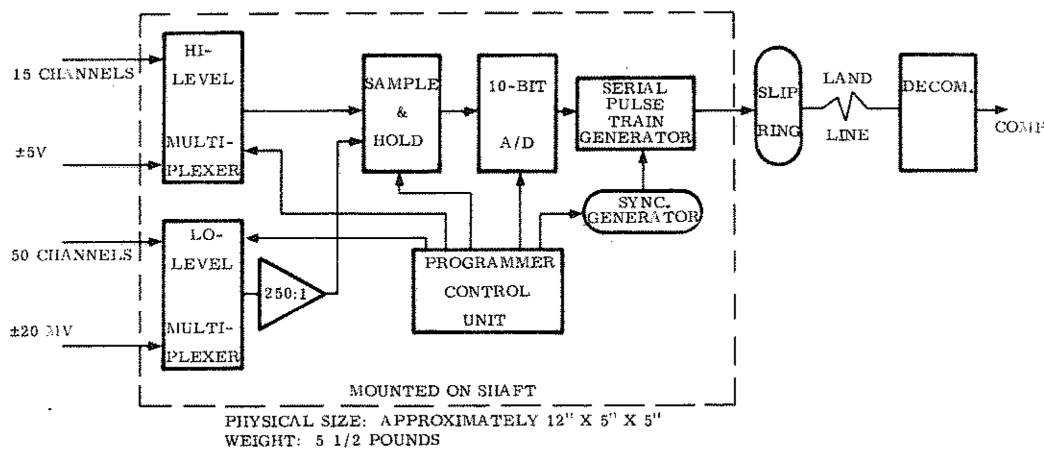

Figure 2. PCM Encoder System Diagram

PCM systems typically operate in a continuous-frame-oriented mode, which requires computer memory space for an integer number of frames. In our case, since only about 30 of the 65 data words in a frame are used (to allow for expansion), much memory space would be wasted. To overcome this problem, the Sandia-designed interface between the PCM decommutator and computer passes only a program-specified group of continuous data words from each frame. This hardware/software match maximizes the number of memory words available for data taken with the PCM system. To aid in implementing this feature, high- and low-level channels are intermingled in the data-word sequence so that a continuous group of data words can be set up. Table I details the parameters of the PCM encoder system. The data-word sequence of 65 words (2 sync words are not included) is outlined in Table I, along with the connector designations. We are now using data words 16 to 46, which give a continuous combination of high- and low-level channels.

TABLE I

PCM Encoder System

S - SYNC DATA WORDS

Two Sync Words (S1 and S2) Per Frame

	MSB									LSB
S1-	1	0	1	0	1	1	0	1	0	1
S2-	0	1	0	0	1	0	1	1	1	0

A - ANALOG DATA WORDS

Fifteen Analog Words. Hi-Level Differential Bipolar
±5.115V Full Scale @ 10.0 MV/Bit
Accuracy: ±0.2% ± 1/2 LSB
±15.22 MV or ±2 1/2 LSB

B - ANALOG DATA WORDS

Eighteen Analog Words. Low-Level Differential Bipolar w/o Filter
±20.46 MV Full Scale @ 40.0 MV/Bit
Accuracy: ±2.2% ±1/2 LSB Max ±1.5% @ 25°C
±0.470 MV or ±12 LSB

C - ANALOG DATA WORDS

Thirty-two Analog Words. Low-Level Differential Bipolar With Filter
±20.46 MV Full Scale @ 40.0 MV/Bit
Accuracy: ±2.2%±1/2 LSB ±1.5% @ 25°C
±0.470 MV or ±12 LSB
Filter: 3 db @ 25 Hz Max 6 dB Per Octave Rolloff

EXCITATION VOLTAGE

Sixty Channels @ 10 Volts ±5 MV into a 350-Ohm Bridge

FRAME STRUCTURE

Bit Rate: 33.5 kHz ±1%
Word Rate: 3.35 kHz ±1% (10 Bits Per Word)
Frame Rate: 50 Hz ±1% (67 Words Per Frame)
Temperature Range: -20°C to +60°C

ITL DIGITAL OUTPUTS

1. Biphase L, MSB First Out Differential Line Driver 7830
2. Frame Rate Strobe, One TTL Load Drive
3. Bit Rate Clock, One TTL Load Drive

ADC OUTPUT CODES

+5.115 ≡ 1 1 1 1 1 1 1 1 1 1
+5.105 ≡ 1 1 1 1 1 1 1 1 1 0
⋮
+0.005 ≡ 1 0 0 0 0 0 0 0 0 0
-0.005 ≡ 0 1 1 1 1 1 1 1 1 1
⋮
-5.105 ≡ 0 0 0 0 0 0 0 0 0 1
-5.115 ≡ 0 0 0 0 0 0 0 0 0 0

TABLE I (cont)

ENCODER POWER CONNECTOR J1

PIN	FUNCTION
1	+28V
2	+28V
3	Case Gnd.
4	-28V Return
5	-28V Return

REGULATED OUTPUT POWER CONNECTOR J8

PIN	FUNCTION
1	+28V
2	+28V
3	Case Gnd.
4	-28V
5	-28V

ENCODER OUTPUT CONNECTOR J2

PIN	FUNCTION
1	Output "AND"
2	Output "NAND"
5	Frame Rate*
6	Bit Rate*
7	Gnd.
8	NR2-L*

*Test points only

NOTE: Output taken between Pins 1 and 7

Analog Input Channels

Channel No.	Channel Type*	Connector and Pins	Function	Channel No.	Channel Type*	Connector and Pins	Function
1	A1	J3-62, 61	Unassigned	34	A8	J3-30, 29	17 M-W.D.
2	A2	J3-10, 9	Unassigned	35	A9	J3-38, 37	Torque-Main Shft.
3	A3	J3-36, 35	Unassigned	36	A10	J3-14, 13	Torque-Motor Shft.
4	A4	J3-60, 59	Unassigned	37	B11	J4-12, 11	Strain Gage 104
5	A5	J3-56, 55	Unassigned	38	B12	J4-64, 63	Strain Gage 105
6	B1	J4-62, 61	Unassigned	39	B13	J4-34, 33	Strain Gage 113
7	B2	J4-10, 9	Unassigned	40	B14	J4-58, 57	Strain Gage 114
8	B3	J4-36, 35	Unassigned	41	C17	J5-46, 45	Strain Gage 115
9	B4	J4-60, 59	Unassigned	42	C18	J5-22, 21	Strain Gage 116
10	B5	J4-56, 55	Unassigned	43	C19	J5-20, 19	Strain Gage 117
11	B6	J4-4, 3	Unassigned	44	C20	J5-72, 71	Strain Gage 303
12	B7	J4-6, 5	Unassigned	45	C21	J5-42, 41	Strain Gage 304
13	B8	J4-30, 29	Unassigned	46	C22	J5-66, 65	Strain Gage 301
14	B9	J4-38, 37	Unassigned	47	C23	J5-16, 15	Strain Gage 302
15	B10	J4-14, 13	Unassigned	48	C24	J5-40, 39	Unassigned
16	C1	J5-62, 61	Strain Gage 104	49	C25	J5-24, 25	Unassigned
17	C2	J5-10, 9	Strain Gage 105	50	C26	J5-48, 47	Unassigned
18	C3	J5-36, 35	Strain Gage 101	51	C27	J5-50, 49	Unassigned
19	C4	J5-60, 59	Strain Gage 102	52	C28	J5-74, 73	Unassigned
20	C5	J5-56, 55	Strain Gage 103	53	C29	J5-18, 17	Unassigned
21	C6	J5-4, 3	Strain Gage 106	54	C30	J5-70, 69	Unassigned
22	C7	J5-6, 5	Strain Gage 107	55	C31	J5-68, 67	Unassigned
23	C8	J5-30, 29	Strain Gage 108	56	C32	J5-44, 43	Unassigned
24	C9	J5-38, 37	Strain Gage 109	57	A11	J3-12, 11	Unassigned
25	C10	J5-14, 13	Strain Gage 110	58	A12	J3-64, 65	Unassigned
26	C11	J5-12, 11	Strain Gage 111	59	A13	J3-34, 33	Unassigned
27	C12	J5-64, 63	Strain Gage 112	60	A14	J3-58, 57	Unassigned
28	C13	J5-34, 33	Strain Gage 113	61	A15	J3-8, 7	Unassigned
29	C14	J5-58, 57	Strain Gage 114	62	B15	J4-8, 7	Unassigned
30	C15	J5-8, 7	Unassigned	63	B16	J4-32, 31	Unassigned
31	C16	J5-32, 31	Unassigned	64	B17	J4-46, 45	Unassigned
32	A6	J3-4, 3	Flex. Displ. Gage	65	B18	J4-22, 21	Unassigned
33	A7	J3-6, 5	17 M-W.V.				

*Type A Chns ± 5.115V Fullscale
Type B Chns ± 20.46MV Fullscale w/0 filters
Type C Chns ± 20.46MV Fullscale w/25H2 Low Pass filter

TABLE I (cont)

PCM Excitation Voltage Channels
(60 -±10V-Shunt Regulated Channels)
(Grouped in Units of 12)

J6-Connector

Pwr Supply Channel No.	Conn. Pins +, -
49	28, 29
50	30, 31
51	32, 33
52	34, 35
53	36, 37
54	38, 39
55	40, 41
56	42, 43
57	44, 45
58	46, 47
59	48, 49
60	50, 51
On/Off 49-60	53, 52
37	54, 55
38	56, 57
39	58, 59
40	60, 61
41	62, 63
42	64, 65
43	66, 67
44	68, 69
45	70, 71
46	72, 73
47	74, 75
48	76, 77
On/Off 37-48	79, 78

J7-Connector

Pwr Supply Channel No.	Conn. Pins +, -
25	2, 3
26	4, 5
27	6, 7
28	8, 9
29	10, 11
30	12, 13
31	14, 15
32	16, 17
33	18, 19
34	20, 21
35	22, 23
36	24, 25
On/Off 25-36	27, 26
13	28, 29
14	30, 31
15	32, 33
16	34, 35
17	36, 37
18	38, 39
19	40, 41
20	42, 43
21	44, 45
22	46, 47
23	48, 49
24	50, 51
On/Off 13-24	53, 52

J7-Connector

Pwr Supply Channel No.	Conn. Pins +, -
1	54, 55
2	56, 57
3	58, 59
4	60, 61
5	62, 63
6	64, 65
7	66, 67
8	68, 69
9	70, 71
10	72, 73
11	74, 75
12	76, 77
On/Off 1-12	79, 80

Another subtle feature of the frame-oriented data sequencing that is useful from a software point of view, is the time segregation effect of framing. At the 50-Hz frame rate, we can consider all the data in one frame as being at the same time point. It is often important to investigate the time relationship between parameters. Very simple software approaches can be used to plot data which is already time-segregated because of the framing action of the PCM encoder. For this reason, high-level analog signals representing wind velocity, wind direction, and torque outputs are passed from the ground through the slip-ring assembly to the PCM encoder.

Strain gages positioned on the blades are designated by a three-digit number,[10] the most significant digit indicating the blade and the lesser digits the gage. One additional feature of this PCM encoder unit is the provision for strain-gage excitation voltage. From the initial planning stages, it has been assumed that the principal transducers employed on the rotating elements of the VAWT would be strain gages. To accommodate this situation, the box containing the PCM encoder also includes 60 10-V, shunt-regulated excitation channels. These channels are physically contained on five printed circuit cards so that any group of 12 excitation channels can be independently turned on or off. Each channel is self-regulating and is therefore independent of possible faults on any other gage channel. The one restriction typical of shunt regulation units is that if a completely open circuit occurs, the regulator circuits demand more current than the power supply can furnish. This has not been a problem; however, if any group of 12 channels are turned on, a 350-ohm load should be placed across any channels not connected to a gage.

Table I includes the PCM encoder connectors indicating pin designations, PCM channel number, functional use, and general parameters of the encoder. It should be noted that the framing rate is programmed at 50 Hz. This implies that 25 Hz is the maximum frequency that should be digitized. This limitation may be overcome by reprogramming the encoder control unit or (in a limited case) connecting the signal in parallel to two evenly spaced channels to give a greater sampling rate to the signal, a form of supercommutation.

Analog-to-Digital Converter - HP-2313

This is the major data input device for the system. The A/D converter is presently equipped with a programmable pacer, 32 channels of high-level, and 16 channels of low-level programmable gain (seven gain steps giving a range between ± 5 MV and ± 1.25 V). All channels are differentially connected to suppress noise. Four empty card slots are available for expansion of up to 64 additional channels.

The HP-2313 can be used in either a random or sequential channel access mode. For application flexibility, we have employed the unit only in the random access mode. In this mode, and including software conversion times, the average reading speed is ~ 150 microseconds per channel requested. The high-level channels have a voltage range of ± 10.24 V, with a 12-bit 2's complement binary word output. Voltage resolution is ~ 5 MV per bit.

The programmable pacer controls the sampling rate at which readings are taken. This can be done under program control using the computer interrupt system. The range of sample rates can be varied from one sample every 2550 seconds to 45,000 samples/s. This sample rate is programmed as a product of a variable microsecond time base between 0 and 255 and an integer power of 10 between 0 and 7.

To make it easier to connect signals to the A/D unit, maintain flexibility, and allow untrained personnel to use the system, all A/D channels are precabled to a connector bank mounted outside the computer enclosure. Connecting a new signal source then involves only mating to the appropriate pins of the connector. It is not necessary to go into the HP 2313 and manipulate internal connectors.

With this approach, modifications can be made to the experiments without risking damage to the A/D converter unit. Table II lists the connector pin and functions for the connectors mounted on the back of the computer rack.

TABLE II

Connector Designations for Computer Rack-Mounted Devices

AN-Connector No. 1

Pins Used	Computer Device	Functional Application
A, B	A/D Chn 13	17/M Hi-Level Torque
C, D	A/D Chn 14	17/M Lo-Level Torque
E, F	A/D Chn 15	17/M Upper Shaft RPM
G, H	A/D Chn 16	17/M Motor Shaft RPM
J, K	A/D Chn 17	17/M 100' Wind Velocity
L, M	A/D Chn 18	17/M 80' Wind Velocity
N, P	A/D Chn 19	17/M 100' Wind Direction
R, S	A/D Chn 20	5/M Torque Output
T, U	A/D Chn 21	5/M Fence Wind Velocity
V, W	A/D Chn 22	5/M Centerline Wind Velocity
X, Y	Relay Chn 10	Unassigned
Z, a	Relay Chn 11	
b, c	Relay Chn 12	
d, e	Relay Chn 13	
f, g	Relay Chn 14	
h, i	Relay Chn 15	
j, k	Relay Chn 16	
m, n	Relay Chn 17	
p, g	Relay Chn 18	
r, s	Relay Chn 19	
t, u	Relay Chn 20	

AN-Connector No. 2

Pins Used	Computer Device	Functional Application
A, B	A/D Chn 23	Tower 12' Velocity
C, D	A/D Chn 24	Tower 34' Velocity
E, F	A/D Chn 25	Tower 58' Velocity
G, H	A/D Chn 26	Tower 100' Velocity
J, K	A/D Chn 27	Tower 12' Direction
L, M	A/D Chn 28	Tower 34' Direction
N, P	A/D Chn 29	Tower 58' Direction
R, S	A/D Chn 30	Tower 100' Direction
T, U	A/D Chn 31	2M Wind Vel.
V, W	A/D Chn 32	2M Wind Dir
X, Y	Relay Chn 21	
Z, a	Relay Chn 22	
b, c	Relay Chn 23	
d, e	Relay Chn 24	
P, g	Relay Chn 25	
h, i	Relay Chn 26	
j, k	Relay Chn 27	
m, n	Relay Chn 28	
p, q	Relay Chn 29	
r, s	Relay Chn 30	
t, u	Relay Chn 31	
v, w	Relay Chn 32	

Jones Strip Block

Screw Pair Connectors	Computer Device	Functional Application
1	A/D Chn 1	Induction Motor Power
2	A/D Chn 2	Induction Motor Current
3	A/D Chn 3	Induction Motor Voltage
4	A/D Chn 4	Sychnc. Gen. Power
5	A/D Chn 5	2M Torque
6	A/D Chn 6	Unassigned
7	A/D Chn 7	
8	A/D Chn 8	
9	A/D Chn 9	
10	A/D Chn 10	
11	A/D Chn 11	
12	A/D Chn 12	
13	Relay Chn 1	
14	Relay Chn 2	
15	Relay Chn 3	
16	Relay Chn 4	
17	Relay Chn 5	
18	Relay Chn 6	
19	Relay Chn 7	
20	Relay Chn 8	
21	Relay Chn 9	
22	A/D Chn 32 (Low Level)	North Guy Wire
23	A/D Chn 33 (Low Level)	South Guy Wire
24	A/D Chn 34 (Low Level)	East Guy Wire
25	A/D Chn 35 (Low Level)	West Guy Wire

Operator's Console and Graphics Plotter

The operator's console is a Tektronix 4014-1 CRT terminal with a mating Tektronix 4631 hardcopy unit. This terminal is a memory scope/keyboard combination that allows for alpha and graphic mode operations. We have provided no other listing device with this system.

In the alpha mode the terminal provides interactive keyboard capability with a 9600-baud output rate. When placed in the graphics mode, the terminal can be used as a high-speed, high-resolution plotter (1024 horizontal points, 780 vertical-axis points).

The 4631 hardcopy unit provides acceptable report-quality copies of the screen contents. Used with the automatic copy command features, the terminal/hardcopy pair can be a moderate-speed listing device or graphic output unit. Tektronix-furnished plotting software has been modified by Sandia Laboratories to provide a hardware/software plotting capability for this system.[9] A key element in the successful use of this system has been the flexibility provided by the terminal/hardcopy pair.

Magnetic Disk System

The system disk is an HP-7905 moving head disk containing one fixed and one removable disk platter. The two surfaces of the removable-disk platter provide a maximum storage capability of 5 million 16-bit words. Only one surface of the fixed platter can be used for storage (the second surface is used for disk control features), providing 2.5 million words. Total active storage for the disk then is 7.5 million 16-bit words. With appropriate program techniques and interchanging removable platters, an "infinite" total storage can be achieved.

Generally, the fixed-disk platter is the depository for the system operating software, while the removable platter acts as the data storage area. But it should be understood that the operating software has equal access to all disk surfaces. Programs and data can be stored and accessed from appropriately named files located on any surface under program control.

Magnetic Tape System

The second mass storage system is an HP-7970E magnetic tape system. This tape system, a 1600-bpi, 45-ips, nine-track, phase-encoded unit, is compatible with tape drives generally found on large central computing facilities. The major reason for procuring the tape system was to provide a convenient way to transfer data between our minicomputer system and other large-scale systems. This option has not been used primarily because of the graphic and analytic capabilities of the minicomputer; there has been no incentive to go to the large-scale systems.

System Software

Operating System Software

The software operating system chosen for the system was HP's DOS III. DOS III supports the following:

1. FORTRAN IV compiler
2. File text editor
3. Named file system

4. Assembler
5. Interrupt and direct memory access (DMA) operations
6. Relocatable loader (capable of loading FORTRAN and assembly-level subroutines)

Although reasonably powerful, the DOS III allows only ~24,000 memory words for the operating user program area. Considering the power of the operating system, this is a very large program area.

The major disadvantages of the DOS III system are its lack of time-oriented tasking functions and the slowness of the compiler and assembler.

A nonstandard FORTRAN feature under DOS known as the "executive," allows FORTRAN programs access to all peripheral devices and the named files. The executive call is a FORTRAN statement resembling the usual subroutine call format. Arguments provided for in the call format specify the operation desired, logical unit involved (if any), file name, number of data words, and relative starting location of data transfer. When executed in an operating program, this executive call uses available monitor routines to perform the specified functions. A programmer familiar with standard FORTRAN subroutine operations can quickly use this feature to access the file system or DMA-type transfers.

Assembly Language Programs

As described above, the executive-call feature provides access to the standard data-handling peripherals (the PCM system interface is designed to have DMA to the system and is controlled then by a variation of the executive call). The A/D converter, relay units and digital-to-analog (D/A) units do not fit under the executive format.

To forestall the need for programmers to write difficult assembly-language routines for these units in each application program, five general-purpose assembly language subroutines are provided. These subroutines may be loaded with a main FORTRAN program and executed by using standard FORTRAN call statements. Arguments are provided to ensure much flexibility in the use of the subroutines. Where appropriate, the arguments are keyed to hardware features of the devices. Under this approach FORTRAN-oriented programmers have full command over all features of the system.

The following are argument descriptions for each call. Appendix A lists each assembly-language routine. Note that the program PADC includes two entry calls, GAIN and PADC.

1. Form of FORTRAN call

   CALL GAIN (N)

   This call varies the gain of the low-level A/D channels. The argument N can be an integer constant or variable name between 1 and 7. Resulting gains are

0 = 1000	4 = 100
1 = 500	5 = 50
2 = 250	6 = 25
3 = 125	7 = 12.5

   The GAIN call sets A/D channels 33 to 48 to the specified gain. If GAIN is not called in the program, a default gain of 500 is in effect.

2. Form of FORTRAN call

   Call PADC (N, ICH, V, IPER, IBASE, IST, NAM)

   N - May be a constant or integer variable; it defines the number of channels to be read.

   ICH - Name of a previously defined array. Array locations from ICH(1) to ICH(N) must be assigned the appropriate channel numbers to be read. Channel number may be in any sequence.

   V - The name of a previously defined floating point array. The floating point voltage results are returned in this array in the sequence in which they are read.

   IPER, IBASE - May be integer constants or variables. These two arguments control the sampling rate at which the A/D unit will operate. IPER must have a value between 0 and 255; this number is a microsecond factor. IBASE must have a value between 0 and 7 and is considered a power-of-10 exponent. IPER equal 1 and IBASE equal 6 specifies a 1-s period. IPER equal 5, IBASE equal 6 specifies a sampling period of 0.5s. If IPER and IBASE equal 0, no interrupts will occur; only the first set of readings will be taken.

   IST - Must be an integer variable name; it must not be an integer constant. IST is employed as a flag for the system. Generally IST is preset to zero (0) prior to making the IST PADC call. Each time the system takes a set of readings, the software will increase IST by N. This allows one to build a logic loop checking the value of IST to determine if a new set of readings has been taken. If IST is set to a negative value when called, the system will use the optional subroutine argument during each interrupt sequence.

   NAM - Must be the name of a subroutine compiled with the main FORTRAN program; the subroutine must contain two arguments N, V. If IST is set negative on the first call, each interrupt sequence will jump to this subroutine setting the correct values for N and V. This feature allows a FORTRAN programmer to accumulate data at a specified interrupt sampling rate while his main program performs other duties. This feature is optional, and the argument NAM may be omitted; if omitted, care must be taken to ensure that IST is not negative when the PADC call is made.

CAUTION

> In all cases where PADC is used, a call to PADC should be made with IPER and IBASE equal 0 before the program is terminated. Failure to do this will cause system monitor errors, as the A/D converter will continue to cause interrupts to a memory area that may be used by the monitor after program termination.

RELAY CONTROL CALL

CALL RELAY (N, ICH)

N - Number of relays affected by the call. Argument may be either an integer constant or variable.

ICH - A predimensioned integer array. Values of ICH(1) to ICH(N) must be assigned arguments representing relay channel numbers. A positive argument will cause the relay to close its normally open contact; a negative argument will open the contact. After a call to RELAY, all relays maintan their settings until the next call.

DIGITAL-TO-ANALOG CONVERTER CALL

CALL DAC (N, ICH, V)

This call is used to obtain program-controlled analog voltages. A voltage range of ± 10 V is obtainable with a 5-MV resolution.

N - May be either an integer variable or constant.

ICH - Must be a predimensioned integer array. The locations ICH(1) to ICH(N) must be assigned values corresponding to the DAC channels to be modified.

V - Must be a predimensioned real array. The locations V(1) to V(N) must be assigned values corresponding to the voltages desired on the corresponding DAC channels.

Appendix C lists the assembly-level programs used to implement these calls.

3. FORTRAN Examples

To illustrate the use of a call in a FORTRAN program, the following program demonstrates the use of PADC. The program reads A/D channels 5, 3 and 4, reading the three channels every 0.25 s. Ten readings are stored in an array group.

```
C - The dimension statement establishes necessary FORTRAN array spaces.
    DIMENSION ICH(10), V(10), STOR1(10), STOR2(10), STOR3(10).
C - The following statements set number of channels to be read,
C - assigns channel numbers, sets the sampling period of 0.25
C - s and finally initializes the flag word IST.
```

```
          N = 3
          ICH(1) = 5
          ICH(2) = 3
          ICH(3) = 4
          IPER = 25
          IBASE = 4
          IST = 0
C - The variable ICOUNT is used to count the number of readings
C - (interrupt sequences).
          ICOUNT = 0
C - The following two lines calls PADC turning on the A/D
C - unit and set in as a comparison value to check for when
C - interrupts have occurred.
          CALL PADC (N, ICH, V, IPER, IBASE, IST)
          IN = IST
C - The following single line loop waits for interrupts to modify IST.
          10 (IN . EQ . IST) GO TO 10
C - The following lines modify IN to match the new value of
C - IST, stores voltage readings into their permanent place
C - and checks the number of interrupts to determine if the pro-
C - gram should terminate.
          IN = IST
          NI = NI + 1
          STOR1(NI) = V(1)
          STOR2(NI) = V(2)
          STOR3(NI) = V(3)
          IF (NI . EQ . 10) GO TO 20
          GO TO 10
C - The final line causes the A/D unit to halt its interrupt
C - processes by calling PADC again with ϕ arguments in the
C - IPER, IBASE positions.
          20 CALL PADC (N, ICH, V, ϕ, ϕ, IST)
          STOP
```

Appendix B is a listing of a FORTRAN program to acquire data from specified PCM channels and automatically plot the data in limits of microstrain vs time in seconds. A review of this program will show that it is almost indistinguishable from a FORTRAN program used on large-scale machines to perform similar scaling and plotting operations.

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APPENDIX A

Assembly-Level Language Programs

```
:LI,S,1,.PADC

ASMB,R,L,F
         NAM %PADC,7
*
        ENT PADC,GAIN
        EXT  .ENTR,EXEC,.GARD
*
*   GAIN SETS GAIN OF  LOW LEVEL MPX
*    CALL GAIN(IG)  WHERE  IG=0 G=1000
*    1=500(DEFAULT),2=250,3=125,4=100
*    5=50, 6=25,7=12.5  (THATS IT)
*
GAN  OCT  1   DEFAULT GAIN OF 500
IG   BSS 1   ARG ADDESS PASSED
GAIN  NOP   ENTRY POINT
     JSB .GARD  GET ARG ADDRESS
        DEF IG
     LDA IG,I   GET GAIN NUMBER
     STA GAN    STORE FOR LATER USE
     JMP GAIN,I  RETURN
*
*
*
*      CALL PADC(N,ICH,V,IBASE,IPER,IST,SUBN)
*      WILL CAUSE PACED READINGS TIMED PER IBASE&IPER
*      SUBN IS OPTIONAL MUST HAVE A NEG. IST WHEN CALLED
*      TO GO  TO SUBN--- CALL WITH IBASE,IPER=0
*      STOPS PACER
*
B EQU 1B
U2313  EQU  11B    SELECT CODE DEFINITION
*
N    BSS 1
ICH  BSS 1
V    BSS 1
IBASE BSS 1
IPER BSS 1
IST  BSS 1
SUBN BSS 1
*
PADC  NOP   ENTRY POINT
      JSB .ENTR   GET ARGUMENTS
      DEF N
*
      LDA MPFLG
      STA MPSAV    SAVING MEM PROTECT STATUS
      SZA
      JMP  MOFF
      JSB  EXEC
      DEF *+3
      DEF RC30
     DEF D1
MOFF  CLF 0
*
*
     CLC U2313
     LDA =B140001  INITALIZE SUB SYSTEM
```

```
      OTA U2313
      STC U2313,C    ENCODE
      NOP
      STC U2313     ENCODE WITH OUT C ?
      SFS U2313
      JMP *-1
*
*
      LDA =B100140  DUMMY READING CN 0 SLOT 3
      OTA U2313
      STC U2313,C
      SFS U2313
      JMP *-1
*
      LDA =B040240  GAIN ENABLE WORD SLOT 5
      OTA U2313
      STC U2313,C
      SFS U2313
      JMP *-1
       LDA GAN  GET GAIN NUMBER
       OTA U2313  SEND OUT
       STC U2313,C
       SFS U2313
       JMP *-1
*
       CLA
      STA FLAG1      IF - NEED SUBN STUFF
      LDA IST,I
      SSA,RSS        SKIP IF -
      JMP POSA       NO FOTRAN SUBN
      STA FLAG1      SAVE - FLAG
POSA  JSB READ
*
        LDA IPER,I  PICK UP MULT. FOR PACER
        ASL 8       SHIFT IT
        LDB IBASE,I  BASE TIME
        IOR 1B       OR IT WITH A
        IOR =B060000  OR REST OF CONTROL
*
*
         LDB TRP   SETTING UP TRAP VECTOR
         STB U2313
         LDB LINK  LINK CONTAINS INTR ADDRESS
         STB 310B  STORE ON BASE PAGE LOCATION
*
         OTA U2313
         STC U2313,C   ENCODE PACE TIME CONTROL
         SFS U2313
         JMP *-1
*
*
      LDA =B130140   DUMMY READING FOR PACED TIME
      OTA U2313
      STC U2313,C
*
```

```
      LDA MPSAV  CHECK OLD FLAG STS
      SZA
      JMP WSOFF
       STF 0
      JSB EXEC
      DEF *+3
      DEF RC30
      DEF D0
      JMP PADC,I
WSOFF  STF 0
      JMP PADC,I  RETURN WAIT FOR INTERRUPTS
*
*
*
PINTR  NOP   ENTRY POINT FOR INTRRUPTS
      CLF 0  NO MORE ALLOWED
      STA SAVA   SAVE REGS A,B,E,O,X,Y
      STB SAVB
      ERA,ALS
      SOC
      INA
      STA SAVEO
      STX SAVX
      STY  SAVY
*
*
        LDA MPFLG  SAVING MPSTS
        STA MPSAV
        CLA,INA
        STA MPFLG
        JSB READ   GO READ
*
        CLC  U2313 DISABLE A/D
       LDA FLAG1  TEST FOR SUBR JUMP
        SSA,RSS
        JMP INT2  JUMP IF -
       LDB SUBN  ADDRESS OF FORT.SUB
       ADB =D-2  FORM ADD. OF N ARG
       LDA N
       STA B,I  STORE ADDRESS LIKE .ENTR WOULD DO
       INB  PUSH POINTER
       LDA V
       STA B,I   STORE V ADDRESS
       INB  ENTRY POINT
       INB   POINT TO JSB .ENTR
       LDA B,I  GOING TO SAVE IT
       STA TEMP1
       CLA
       STA B,I   NOP OLD INST
       INB      POINT TO DEF N+1 LOC.
       LDA B,I
       STA TEMP2
       CLA
       STA B,I
       JSB SUBN,I   GO DO IT
       LDB SUBN   GOING TO RESTORE
       INB
       LDA TEMP1
       STA B,I
       INB
```

```
              LDA TEMP2
              STA B,I
       INT2    NOP
                LDB MPSAV   CHK ON ORIG MP STS
                 SZB
                JMP MPOFF
                STB MPFLG
                JSB RESTR
                LDA =B110140   PACED DUMMY READING
                OTA U2313
                LDA SAVA
                STC U2313,C
                STF 0
                STC 5
                JMP PINTR,I
      MPOFF   STB MPFLG    RESTORE STS WORD
                JSB RESTR     REGS RES"ORED
                LDA =B110140
                OTA U2313
              LDA SAVA
              STC U2313,C
              STF 0
              JMP PINTR,I
      *
      *
      *
      RESTR    NOP
               LDA SAVEO
               CLO
               SLA,ELA
               STF 1
               LDA SAVA
               LDB SAVB
               LDX SAVX
               LDY SAVY
               JMP RESTR,I
      *
      SAVEO     NOP
      SAVA      NOP
      SAVB      NOP
      SAVX      NOP
      SAVY      NOP
      *
      READ     NOP    READ SUB
               LDA N,I  GET NUMOF READS
                CMA,INA   MAKE NEG
                STA TAG    STORE IN COUNT LOC.
           LDA ICH  ADDRESS OF CHNS
           STA TAG+1 STORE IN TEMP LOCATION
           LDA V   ADDRESSOF RESULTS
           ADA =D-2  SUBT 2 FOR LOOP
           STA TAG+2
      *
      LOOP  LDA TAG+1,I  GET CHN NUM
```

```
         ADA =D-33   TEST FOR LLMPX CHN 33-48
         SSA,RSS  SKIP CHN < 33 A IS -
         JMP LLMPX
         LDA TAG+1,I  RESTORE A
         ADA =D-17  TST FOR HLMPX CHNS 17-32
         SSA
         JMP LOOP1  CHN NUN 1-16
         ALS  FORM (N-1)*2
         IOR =B100200  MPX SLOT 4
         JMP CONT
LLMPX    ALS
         IOR =B100240  SLOT 5 LLMPX
         JMP CONT
*
*
LOOP1    LDA TAG+1,I  GET CHN NUM
         ADA =D-1    CONVERT TO DIFF CHN NUM
         ALS       (N-1)*2
*
         IOR =B100140  FORM MPX,RANDOM,BOX 0,SLOT 3 CHN NUM
CONT     OTA U2313   MOV CONTROL WRD
         STC U2313,C
         SFS U2313
         JMP *-1
         LIA U2313  GET DATA
         ISZ TAG+1
         ISZ IST,I  INC IST TO SHOW LIFE
         NOP      IN CASE WE GET A 0 ABOVE
         ISZ TAG+2
         ISZ TAG+2  INC FLOATING POINT ADDR 2X'S
         ARS,ARS
         ARS,ARS   SHIFT OUT STS BITS FROM DATA
         FLT     FLT 12 BITS TO A,B REGS
         FMP FACTR  MULT BY CON FACTOR
         DST TAG+2,I  STORE RESULT
         ISZ TAG    ARE WE DONE
         JMP LOOP
         JMP READ,I  RETURN FROM SUB
*
*
MPSAV    NOP
TAG      BSS 3
D0       DEC 0
D1       DEC 1
RC30     DEC 30
FACTR    DEC .005
TRP      JSB PLINK,I
PLINK    EQU 310B
LINK     DEF PINTR
MPFLG    EQU 271B
FLAG1    NOP
CLRCN    CLC U2313
TEMP1    NOP
TEMP2    NOP
*
         END
**** LIST END ****
@
```

APPENDIX B

FORTRAN Program STRAN
(Acquires data from the PCM and provides plotting capability)

```
:LI,S,1,.IADC

ASMB,R,L,F
              NAM %IADC,7
*    THIS SUB RETURNS INTEGER VALUES FROM THE A/D CONVERTER
*
            ENT IADC,IGAIN
            EXT  .ENTR,EXEC,.GARD
*
*   GAIN SETS GAIN OF  LOW LEVEL MPX
*    CALL GAIN(IG)  WHERE  IG=0 G=1000
*    1=500(DEFAULT),2=250,3=125,4=100
*    5=50, 6=25,7=12.5  (THATS IT)
*
GAN  OCT  1   DEFAULT GAIN OF 500
IG   BSS 1   ARG ADDESS PASSED
IGAIN  NOP  ENTRY POINT
           JSB .ENTR  GET ARG ADDRESS
            DEF IG
        LDA IG,I   GET GAIN NUMBER
        STA GAN    STORE FOR LATER USE
           JMP IGAIN,I  RETURN
*
*
*
*     CALL IADC(N,ICH,IBUFF,IBASE,IPER,IST,SUBN)
*     RETURNS INTEGER ARRAY IN IBUFF OTHERWISE LIKE PADC
*     WILL CAUSE PACED READINGS TIMED PER IBASE&IPER
*     SUBN IS OPTIONAL MUST HAVE A NEG. IST WHEN CALLED
*     TO GO  TO SUBN--- CALL WITH IBASE,IPER=0
*     STOPS PACER
*
B EQU 1B
U2313  EQU  11B    SELECT CODE DEFINITION
*
N    BSS 1
ICH  BSS 1
U    BSS 1
IBASE BSS 1
IPER BSS 1
IST  BSS 1
SUBN BSS 1
*
IADC   NOP  ENTRY POINT
         JSB .ENTR   GET ARGUMENTS
         DEF N
*
         LDA MPFLG
         STA MPSAV    SAVING MEM PROTECT STATUS
         SZA
         JMP  MOFF
         JSB  EXEC
         DEF *+3
         DEF RC30
        DEF D1
MOFF   CLF 0
*
*
        CLC U2313
```

```
      LDA =B140001  INITALIZE SUB SYSTEM
      OTA U2313
      STC U2313,C    ENCODE
      NOP
      STC U2313     ENCODE WITH OUT C ?
      SFS U2313
      JMP *-1
*
*
      LDA =B100140  DUMMY READING CN 0 SLOT 3
      OTA U2313
      STC U2313,C
      SFS U2313
      JMP *-1
*
      LDA =B040240  GAIN ENABLE WORD SLOT 5
      OTA U2313
      STC U2313,C
      SFS U2313
      JMP *-1
       LDA GAN  GET GAIN NUMBER
       OTA U2313  SEND OUT
       STC U2313,C
       SFS U2313
       JMP *-1
*
       CLA
      STA FLAG1     IF - NEED SUBN STUFF
      LDA IST,I
      SSA,RSS       SKIP IF -
      JMP POSA      NO FOTRAN SUBN
      STA FLAG1     SAVE - FLAG
POSA   JSB READ
*
        LDA IPER,I  PICK UP MULT. FOR PACER
        ASL 8       SHIFT IT
        LDB IBASE,I  BASE TIME
        IOR 1B       OR IT WITH A
        IOR =B060000  OR REST OF CONTROL
*
*
         LDB TRP   SETTING UP TRAP VECTOR
         STB U2313
         LDB LINK  LINK CONTAINS INTR ADDRESS
         STB 310B  STORE ON BASE PAGE LOCATION
*
         OTA U2313
         STC U2313,C   ENCODE PACE TIME CONTROL
         SFS U2313
         JMP *-1
*
*
      LDA =B130140   DUMMY READING FOR PACED TIME
      OTA U2313
      STC U2313,C
*
      LDA MPSAV  CHECK OLD FLAG STS
      SZA
      JMP WSOFF
       STF 0
      JSB EXEC
```

```
       DEF *+3
       DEF RC30
       DEF D0
         JMP IADC,I
WSOFF    STF 0
         JMP IADC,I
*
*
*
PINTR    NOP    ENTRY POINT FOR INTRRUPTS
       CLF 0  NO MORE ALLOWED
       STA SAVA   SAVE REGS A,B,E,O,X,Y
       STB SAVB
       ERA,ALS
       SOC
       INA
       STA SAVEO
       STX SAVX
       STY  SAVY
*
*
         LDA MPFLG  SAVING MPSTS
         STA MPSAV
         CLA,INA
         STA MPFLG
         JSB READ   GO READ
*
         CLC  U2313 DISABLE A/D
        LDA FLAG1  TEST FOR SUBR JUMP
         SSA,RSS
         JMP INT2  JUMP IF -
        LDB SUBN  ADDRESS OF FORT.SUB
        ADB =D-2  FORM ADD. OF N ARG
        LDA N
        STA B,I  STORE ADDRESS LIKE .ENTR WOULD DO
        INB  PUSH POINTER
        LDA V
        STA B,I   STORE V ADDRESS
        INB  ENTRY POINT
        INB   POINT TO JSB .ENTR
        LDA B,I  GOING TO SAVE IT
        STA TEMP1
        CLA
        STA B,I   NOP OLD INST
        INB     POINT TO DEF N+1 LOC.
        LDA B,I
        STA TEMP2
        CLA
        STA B,I
        JSB SUBN,I   GO DO IT
        LDB SUBN   GOING TO RESTORE
        INB
        LDA TEMP1
        STA B,I
        INB
        LDA TEMP2
        STA B,I
INT2     NOP
          LDB MPSAV  CHK ON ORIG MP STS
           SZB
```

```
          JMP MPOFF
          STB MPFLG
          JSB RESTR
          LDA =B110140  PACED DUMMY READING
          OTA U2313
          LDA SAVA
          STC U2313,C
          STF 0
          STC 5
          JMP PINTR,I
MPOFF     STB MPFLG   RESTORE STS WORD
          JSB RESTR    REGS RESTORED
          LDA =B110140
          OTA U2313
          LDA SAVA
          STC U2313,C
          STF 0
          JMP PINTR,I
*
*
*
RESTR     NOP
          LDA SAVEO
          CLO
          SLA,ELA
          STF 1
          LDA SAVA
          LDB SAVB
          LDX SAVX
          LDY SAVY
          JMP RESTR,I
*
SAVEO     NOP
SAVA      NOP
SAVB      NOP
SAVX      NOP
SAVY      NOP
*
READ      NOP    READ SUB
          LDA N,I  GET NUMOF READS
          CMA,INA   MAKE NEG
          STA TAG    STORE IN COUNT LOC.
      LDA ICH  ADDRESS OF CHNS
      STA TAG+1 STORE IN TEMP LOCATION
      LDA V   ADDRESSOF RESULTS
        ADA =D-1  SUBT 1 FOR LOOP
      STA TAG+2
*
LOOP   LDA TAG+1,I  GET CHN NUM
       ADA =D-33   TEST FOR LLMPX CHN 33-48
       SSA,RSS  SKIP CHN < 33 A IS -
       JMP LLMPX
       LDA TAG+1,I  RESTORE A
       ADA =D-17  TST FOR HLMPX CHNS 17-32
       SSA
       JMP LOOP1  CHN NUN 1-16
       ALS  FORM (N-1)*2
       IOR =B100200  MPX SLOT 4
       JMP CONT
LLMPX   ALS
```

```
          IOR =B100240  SLOT 5 LLMPX
           JMP CONT
*
*
LOOP1     LDA TAG+1,I  GET CHN NUM
          ADA =D-1    CONVERT TO DIFF CHN NUM
          ALS       (N-1)*2
*
         IOR =B100140  FORM MPX,RANDOM,BOX 0,SLOT 3 CHN NUM
CONT      OTA U2313   MOV CONTROL WRD
          STC U2313,C
          SFS U2313
          JMP *-1
          LIA U2313  GET DATA
          ISZ TAG+1
         ISZ IST,I  INC IST TO SHOW LIFE
          NOP       IN CASE WE GET A 0 ABOVE
          ISZ TAG+2  INC ADDRESS TO STORE RESULT
          ARS,ARS
          ARS,ARS   SHIFT OUT STS BITS FROM DATA
          STA TAG+2,I  STORE REULT INTEGER
          ISZ TAG    ARE WE DONE
          JMP LOOP
          JMP READ,I  RETURN FROM SUB
*
*
MPSAU      NOP
TAG       BSS 3
D0        DEC 0
D1        DEC 1
RC30      DEC 30
FACTR     DEC .005
TRP       JSB PLINK,I
PLINK     EQU 310B
LINK      DEF PINTR
MPFLG     EQU 271B
FLAG1     NOP
CLRCN      CLC U2313
TEMP1     NOP
TEMP2      NOP
*
          END
**** LIST END ****
@
```

```
:LI,S,1,.RELA

ASMB,R,L,F
      NAM %RELA,7
      ENT RELAY
      EXT .GARD,EXEC
*
REL1  EQU 22B
REL2  EQU 23B
MPFLG EQU 271B
*
NR  BSS 1
IRE BSS 1
RELAY  NOP  ENTRY -CALL RELAY(NR,IRE)
*           IRE IS INT. ARRAY
*
        JSB .GARD  GET ARGUMENTS
        DEF NR
*
       LDA MPFLG   SAVE MP STS
       STA MPSAV
       SZA         SKIP IF ON
       JMP MPOFF
       JSB EXEC    TURN MP OFF
       DEF *+3
       DEF RC30
       DEF D1
*
MPOFF  LDA NR,I  GET NUM OF CHNS TO BE MODIFIED
       CMA,INA    NEGATE IT
       STA NARGS
*
START  LDA IRE,I  GET FIRST CHN ADDRESS
       ISZ IRE    BUMP POINTER
       SZA,RSS    SKIP IF CHN ADD NOT 0
       JMP FINIS  DONE  NO CHN 0
*
       SSA       IF + CHN ADDRESS SKIP
       JMP MINUS  GO OPEN RELAY
       JSB CHOSC  GET CONTROL WORD
       ADA =D-1   DEC A  CORRECT FOR 0 BIAS
       SZA,RSS    SKIP IF NOT 0 WILL NOT SHIFT BIT
       JMP AROSF  JMP AROUND SHIFT
       IOR SHFTI  OR IN SHIFT INST
       STA SHFT   STORE IT IN LINE
       CLA,INA
SHFT   NOP         SHIFT INST WILL BE HERE
ARO    IOR CONWD  OR IN CONTROL 1 OR 2
       STA CONWD  PRESERVE MODIFIED WORD
*
       ISZ NARGS  DONE?
       JMP START  NO
       JMP FINIS  YES
*
AROSF   CLA,INA   TAKES CARE OF NO SFIFT CASE
       JMP ARO
*
*
MINUS   CMA,INA   GET ITS POSITIVE VALUE
```

```
         JSB CHOSC GO PICK CONWRD
         ADA =D-1  DEC A FOR 0 COMPATABILITY
         SZA,RSS
         JMP AROS1    JMP IF A=0
      IOR SHFTI OR IN SHFT INST
      STA SHFT1
      CLA,INA   PLACE 1 IN BIT 0
SHFT1  NOP
AR01   CMA  COMPLIMENT BIT WORD
       AND CONWD
       STA CONWD  SAVE IT
        JMP START
*
AROS1  CLA,INA
       JMP AR01
*
FINIS  LDB CONWD
       OTB REL1  IST WRD OUT
       LDB CONW2
       OTB REL2
*
       LDA MPSAV
        SZA
       JMP WSOFF
       JSB EXEC
       DEF *+3
       DEF RC30
       DEF D0
WSOFF  JMP RELAY,I
*
*
*
*  SUB TO PICK CORRECT CONTROL WORDS TO
*  BE MODIFIED  WORDS ARE THEN PUT
*  IN PROGRAM LINE
*
CHOSC  NOP
       CAY  SAVE A IN REG Y
       ADA =D-16  16 CHN LIMIT ON CARD
       SZA,RSS  IF 0='S 16
       JMP E16
       SSA,RSS  SKIP ON NEG
       JMP GT16
E16    CYA     GET A BACK  COME HERE FOR =16 OR
       LDB BANK1   LT 16
       STB ARO
        LDB BANK1+1
       STB ARO+1
       STB AR01+2
       LDB BANK1+2
       STB AR01+1
       JMP CHOSC,I
*
GT16   LDB BANK2
```

```
           STB ARO
           LDB  BANK2+1
           STB ARO+1
            STB ARO1+2
           LDB BANK2+2
           STB ARO1+1
           JMP CHOSC,I
*
D16   DEC 16
RC30  DEC 30
D1    DEC 1
D0    DEC 0
SHFTI OCT 100020
CONWD NOP
CONW2 NOP
*
BANK1 IOR CONWD
      STA CONWD
      AND CONWD
BANK2  IOR CONW2
      STA CONW2
      AND CONW2
NARGS NOP
MPSAV NOP
*
      END
**** LIST END ****
@
```

```
:LI,S,1,.DAC

ASMB,R,L,F
      NAM %DAC,7
      ENT DAC
      EXT .ENTR,EXEC
*
UMP   EQU 10B
MPFLG EQU 271B
*
NN    BSS 1  NUM OF CHNS TO BE MODIFIED
ICN   BSS 1  INT. ARRAY FOR CHN NUMS
VMO   BSS 1  REAL ARRAY FOR OUTPUT V'S
*
DAC   NOP    ENTRY--CALL DAC(NN,ICN,VMO)
      JSB .ENTR
      DEF NN
*
      LDA MPFLG   CHK MP STS
      STA MPSAV   SAVE PRESENT STS
      SZA         SKIP IF MP ON
      JMP MPOFF
      JSB EXEC
      DEF *+3     CALL EXEC MP TURN OFF
      DEF RC30
      DEF D1
*
MPOFF LDA NN,I   GET NUM OF CHNS
      CMA,INA    NEGATE IT
      STA NLOOP  SAVE FOR LOOP INCREMENTING
*
LOOP  LDA ICN,I  GET FIRST CHN TO BE MODIFIED
      ISZ ICN    INC POINTER
      ADA =D-1   SUB 1 FOR 0 CHN BIAS
      STA TEMP   SAVE IT
      LDB CON1   GET CONTROL WRD
*                CONTROL WORD CONDITIONS DACS
       OTB UMP   OUT PUT IT
      NOP         STALL 8 USEC PER BOOK
      NOP
      NOP
      NOP
      NOP
      STC UMP,C  ENCODE CONTROL
      SFS UMP    SPIN UNTILL IT ACCEPTS CONTROL
      JMP *-1
*
      DLD VMO,I  GET 1ST VOLTAGE
      ISZ VMO    INC POINTER
      ISZ VMO    2ND TIME REAL ARRAY
      FMP FCTR   MULT BY 12 BIT FACTOR
      FIX        FIX TO INTEGER IN REG A
      AND =B007777  CLR UPPER 4 SLOT BITS
*                 THESE HOLD CHN ID
      LDB TEMP    GET CHN NUM
      BLF        SHIFT 12 BITS
      BLF
      BLF
      IOR 1B     OR TO REG A
```

```
*
         OTA UMP
         NOP
      NOP
      NOP
      NOP
      NOP
      STC UMP,C
*                   NO WAIT FOR FLAG
      ISZ NLOOP   DONE?
      JMP LOOP    NO
*
      LDA MPSAV   RESTORE MP AS NEEDED
         SZA
      JMP WSOFF
      JSB EXEC
      DEF *+3
      DEF RC30
      DEF D0
*
WSOFF   JMP DAC,I
*
NLOOP    NOP
CON1     OCT 170160
FCTR     DEC 200.45
RC30     DEC 30
D1       DEC 1
D0       DEC 0
TEMP     NOP
MPSAV    NOP
         END
**** LIST END ****
@
```

:LI,S,1,STRAN

```
FTN4,L
      PROGRAM SPLI(3)
      COMMON TCS(134)
      DIMENSION IDATA(8000),IBUFF(256),ICHAN(5,5),ITV(6),ITH(5),
     1   STRAN(1000),TIME(1000),GSCAL(64),NAME1(3),IZERO(64)
     1  ,IVEL(3)
      EQUIVALENCE(GSCAL(1),IBUFF(129)),(IZERO(1),IBUFF(65))
      DATA ITV/2HMI,2HCR,2HCS,2HTR,2HAI,2HN /
      DATA ITH/2HTI,2HME,2H(M,2HSE,2HC)/
      DATA IVEL/2HV(,2HMP,2HH)/
      DATA NAME1/2HGA,2HGE,2H  /
      ID = 2H*
      CALL EXEC(23,ID)
      CALL EXEC(18,NAME1,ISECT,0)
      IF(ISECT .NE. 0)GO TO 5
      WRITE(1,17)
   17 FORMAT("GAGE FILE NOT FOUND")
      STOP
    5 CALL EXEC(14,2B,IBUFF,256,NAME1,0)
      WRITE(1,101)
  101 FORMAT("PCM CHANNEL",5X,"GAGE NUMBER",5X,
     1  "ZERO OFFSET",5X,"SCALE FACTOR")
      DO 103 I = 1,64
      IF(GSCAL(I) .EQ. 0.) GO TO 103
  102 FORMAT(5X,I2,12X,I4,14X,I4,10X,E10.4)
      WRITE(1,102) I, IBUFF(I),IZERO(I),GSCAL(I)
  103 CONTINUE
      WRITE(1,115)
  115 FORMAT("TO CHANGE CHANNEL NUMBERS, RUN PROG STRES")
C
    2 DO 1 I = 1,5
      DO 1 J = 1,5
    1 ICHAN(I,J) = 0
      WRITE(1,10)
   10 FORMAT("ENTER NUMBER OF LINES TO PLOT(MAX OF 4)")
      READ(1,*) NLINE
      N = 1
   15 WRITE(1,11) N
   11 FORMAT("ENTER CHANNEL NUMBERS FOR LINE ",I2)
      I = 1
      READ(1,*) NO
      ICHAN(N,I) = NO
   13 IF(N .GE. NLINE) GO TO 27
      N = N + 1
      GO TO 15
   27 CONTINUE
      N = NLINE + 1
      ICHAN(N,1) = 33
   29 WRITE(1,28)
   28 FORMAT("ENTER NUMBER OF PCM SCANS FOR PLOTTER")
      READ(1,*)NSCNS
      ICHMN = 64
      ICHMX = 1
      DO 31 I = 1,5
      DO 31 J = 1,5
      IF(ICHAN(I,J).EQ.0)GO TO 31
      IF(ICHAN(I,J) .LT.ICHMN)ICHMN = ICHAN(I,J)
```

```
      IF(ICHAN(I,J).GT.ICHMX)ICHMX = ICHAN(I,J)
   31 CONTINUE
      NCH = ICHMX-ICHMN+1
      LDATA = NCH*NSCNS
      IFBCD = ICHMN
      ILBCD = ICHMX
      CALL BNBCD(IFBCD)
      CALL BNBCD(ILBCD)
       IF (LDATA .GT. 8000)GOTO 29
      IDATA(1) = IFBCD
      IDATA(2) = ILBCD
      CALL EXEC(1,107B,IDATA,LDATA)
      CALL PCSCL(IDATA,LDATA)
      NL = 1
   33 K = 1
      IT = 0
      DO 32 I = 1,LDATA
      IU = (I-1)/NCH
      ICH = I - IU*NCH + ICHMN - 1
      IF(ICH.NE.ICHAN(NL,K))GO TO 32
      IT = IT + 1
      IF(IT .GE. 1000) STOP 30
      TIME(IT) = .3*FLOAT(ICH) + FLOAT(IU)*20.
      SDATA = (IDATA(I) - IZERO(ICH))
      STRAN(IT) = SDATA*GSCAL(ICH)
      K = K + 1
      IF(ICHAN(NL,K) .EQ. 0) K = 1
   32 CONTINUE
      IF(NL .GT.NLINE) GO TO 47
      IF(NL .GT. 1) GO TO 46
      CALL PLOTS
      I1 = IT + 1
      I2 = IT + 2
      STRAN(I1) = -1000.
      STRAN(I2) = 500.
      IF(I2 .GE. 1000) STOP 31
      CALL SCALE(TIME,6.,IT,1)
      CALL AXIS(.5,.5,ITH,-10,6.,0.,TIME(I1),TIME(I2))
      CALL AXIS(.5,.5,ITV,12,5.,90.,STRAN(I1),STRAN(I2))
      CALL TGRID(.5,6.5,.5,5.5)
      CALL PLOT(.5,.5,-3)
   46 CALL LINE(TIME,STRAN,IT,1,0,NL)
      NL = NL + 1
      GO TO 33
   47 CALL PLOT(0.,3.0,-3)
      CALL AXIS(6.,0.,IVEL,-6,2.,90.,0.,30.)
      STRAN(I1) = 0.
      STRAN(I2) = 30.
      CALL LINE(TIME,STRAN,IT,1,5,NL)
   48 CALL ANMDE
      CALL TINPT(M)
      CALL PLOT(0.,0.,999)
      WRITE(1,50)
   50 FORMAT("MORE PLOTS?")
      READ(1,117) IANS
  117 FORMAT(A2)
      IF(IANS .EQ.2HYE) GO TO 2
      STOP
      END
      END$
**** LIST END ****
@
```

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