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An Overview of the Division 2351 Neutron Generator Test Facility Waveform Digitizing System

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AN OVERVIEW OF THE DIVISION 2351 NEUTRON
GENERATOR TEST FACILITY WAVEFORM DIGITIZING SYSTEM

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ABSTRACT

All neutron generator waveforms from units tested at the SLA neutron generator test site are digitized and the digitized data stored in the CDC 6600 tape library for display and analysis using the CDC 6600 computer. The digitizing equipment consists mainly of seven Biomation Model 8100 transient recorders, Digital Equipment Corporation PDP 11/20 computer, RK05 disk, seven-track magnetic tape transport, and appropriate DEC and SLA controllers and interfaces. The PDP 11/20 computer is programmed in BASIC with assembly language drivers. In addition to digitizing waveforms, this equipment is used for other functions such as the automated testing of multiple-operation electronic neutron generators. Although other types of analysis have been done, the largest use of the digitized data has been for various types of graphical displays using the CDC 6600 and either the SD4020 or DX4460 plotters.

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I. INTRODUCTION

Both explosive and electronic neutron generators are tested at the Division 2351 Test Facility during the development of neutron generators for various weapon and laboratory applications. Since the explosively activated neutron generators are one-shot devices, it is important to have the data digitized to get maximum information from each unit expended. The electronic units are frequently field test and experimental neutron generators which may require 400 operations each, with 2 or more waveforms recorded per operation. The magnitude of this data quickly swamps any analysis based on oscilloscope photos of the waveforms. Even if little analysis of data were required, just the storing and recovery of the thousands of waveforms generated during the development of a neutron generator would require some digitizing method. A system to digitize the neutron generator waveforms and store them on magnetic tape in the CDC 6600 computer library is operational, and some analysis of the data has been accomplished.

More detailed information on the system is available.⁽¹⁾ This report is intended to present an overview of the system for readers who need to understand generally how the neutron generator waveforms are digitized and stored but have no interest in details. A few examples of analysis of the digitized data are included.

II. OUTLINE OF THE DIGITIZING SYSTEM

Figure 1 is a block diagram of the entire digitizing system. To avoid confusion between the terms "digitizer" and "digitizing system", the "digitizer" has been defined as the hardware and software physically located in the test

OMEGA 8100 TRANSIENT RECORDERS

AREA 2 BLD 935

FLOW CHART OF THE DIGITIZING AND ANALYSIS SYSTEM

Figure 1

facility which is located in Bldg. 935 in Area II. The "digitizing system" includes the digitizer and all of the hardware and software located in Area I, including the CDC 6600 computer, CDC 6600 tape library, and all Fortran programming used for format conversion, analysis, and display of the digitized data.

Although the Biomation Model 8100 transient recorders digitize 2024 data words, with a sampling interval as short as 10 nanoseconds available, only 1000 data words are software selected with a time interval of 20 nanoseconds. Neutron generator waveforms are represented accurately by 1,000 points across the waveform, and a 20 microsecond record time is convenient for relating the various neutron generator waveforms with each other.

The data is put into memory with a DMA (Direct Memory Access) transfer and is then converted to external BCD and transferred to seven-track magnetic tape.

The identification record is then created using a combination of keyboard and automatic entries using BASIC. The ID record is then converted from ASCII to external BCD and transferred to the magnetic tape.

When the test is completed, the tape and a Fortran program is sent to the CDC 6600 where the format is changed and the data transferred to the library tape. The data is then available for the various display and analysis programs currently in use. The analysis and display programs are input under NOS (Network Operating System), the remote terminal in Bldg. 802, or by card input to the CDC 6600 computer center.

III. DIGITIZER HARDWARE

Figures 2 and 3 are photographs of the instrumentation room of the test facility including the digitizer. The Biomation Model 8100 transient recorders are distributed at convenient locations throughout the instrumentation room. The stations are addressed so the transient recorders may be moved around in the event of a transient recorder failure during a test.

Figure 4 is a block diagram of the digitizer hardware as it is presently configured. The bottom four interfaces have been added recently by SLA to automate the testing of electronic neutron generators and to use with the new calibration system. The other interfaces are standard DEC (Digital Equipment Corporation) interfaces, except for the Biomation Model 8100 transient recorder interface which was provided by DEC Special Systems. More information on the hardware is available,⁽¹⁾⁽²⁾ but the block diagram should be adequate for a quick overview of the hardware.

IV. CALIBRATION

Two methods are used for calibration of the transient recorders. The original calibrator applies a known voltage to the transient recorder input. This input is digitized and a calibration factor calculated by the BASIC program. This method is still used to eliminate any drift of the transient recorder circuitry, and is done before each operation of the transient recorder. In addition to this method, before each neutron generator test, a set of waveforms which simulate the neutron generator to be tested are generated by a special signal generator which is physically located in place of the neutron generator. The waveforms from the signal generator are used to arrive at calibration factors to compensate for voltage drops

Figure 2

Figure 3

INSTRUMENTATION/COMPUTER ROOM

Figure 4

in cables, attenuators that are not at their rated values, and to check for incorrect cable hookup. The BASIC program checks the digitized amplitude of each waveform and calculates a calibration factor for each transient recorder based on the known amplitude of the signal at the signal generator and the amplitude of the digitized waveform. The trailing slope of the flat-topped waveform from the signal generator may also be used to check the input amplifier crossover of the Biomation Model B100. The signal generator is calibrated and certified by the SLA Standards Department.

There is a BASIC program used to check the transient recorders on an occasional basis. It uses a one-megahertz sine wave input and checks for the fit of the digitized waveform to a one-megahertz sine wave.

V. DIGITIZER SOFTWARE

The digitizer software consists of the DEC system programs PIP (Peripheral Interchange Program), TECO (Text Editor & Corrector), ROLLIN, RT11 Monitor, a SLA modified version of DEC's BASIC, and assembly language drivers.

A separate BASIC program is written for each type of neutron generator to be tested. These programs, which are stored on the disk, call the same set of assembly language drivers which are seldom modified. Documentation of the assembly language drivers exists,⁽²⁾ but only an outline of the functions of the drivers presently in use will be covered here.

The transient recorders are under complete computer control by a combination of the BASIC program and an assembly language program called TRCONT.

The BASIC programs used to test a neutron generator with an output of several waveforms is so long that some modifications to the programs have been made to stay in the BASIC user area. Storing the data on the disk saved 900 words since the length of the array used to hold this data for local analysis and CRT display could be changed from 1000 to 100 and the data transferred to the disk in 100-word blocks. Even with this change, some programs require stripping of some remark (REM) statements. A typical program contains 460 lines of code. Since programs continue to grow in size, the next step will be to keep a text copy of the program with remark statements and an operating program with no remark statements. So far, overlays have not been considered.

With the "PUT", "GET", "TBIT", and "SBIT" features of the BASIC presently used, much of the very expensive assembly language programming could now be avoided, although the DMA transfer of the data from the transient recorders would probably still be required since transfer under BASIC would be too slow. All new interfaces are programmed in BASIC. Since the assembly language programs exist and work well, no consideration has been given to changing any of the operating assembly language drivers to BASIC.

Figure 5 illustrates the digitizer software. The flow chart is in the same sequence as the software would normally be used to remove the data from one transient recorder and transfer its data and an identification record to seven-track magnetic tape for transfer to the CDC 6600. The comments used in Figure 5 should be adequate for an overview of the software. More details are available. (1)(2)

Figure 5

SOFTWARE FLOW CHART

Figure 5 (cont.)

Figure 5 (cont.)

VI. DIGITIZING ADVANTAGES AND COMPUTER CONTROL

Prior to the digitizer, the neutron detector spacing to the unit and photomultiplier voltage had to be selected to establish a value called Q . Q was used to establish neutron sensitivity and is equal to the ratio of the total neutrons read from the scaler and the integral of the analog signal in volt-microseconds from the electronic integrator. A rate level was set on the oscilloscope. Earlier computer programs used with the digitizer also used the rate in neutrons and volts to calculate sensitivity. Since the computer is interfaced to the scaler and can determine the integral of the prompt neutron pulse, the sensitivity is now derived by the computer from each neutron waveform. In addition to greatly reducing setup time, accuracy is increased since any drift in the neutron detector electronics will have no effect on the sensitivity.

The new calibration system has increased the accuracy of the digitized data to the point that the oscilloscopes which back up the digitizer are calibrated monthly instead of before each test. Rate lines are no longer set on the scopes. Scopes have been dropped completely from electronic unit testing but are still used as back-up on one-shot explosive unit testing.

Another advantage of using digitized data is the fact that timing corrections can be made by the computer to the digitized data to compensate for inherent delays in timing and unequal cable lengths between the signal and trigger to the transient records.

Completely automated testing of electronic units is now done routinely using interfaces to the neutron detector scaler, timer, and DEC relay chassis. This saves typically 75 minutes of operator time per unit and as much as 6.5 hours per unit on some life testing.

The computer is used for several site operations other than digitizing neutron generator waveforms, and more computer control is planned. Some examples of using the computer for test site operations are:

A. HI-POT

In this case, the voltage applied to the unit under test is digitized to measure the applied voltage and a printout generated for each voltage applied. The printout includes the unit serial number, temperature of the unit, applied voltage and voltage breakdown, if any.

B. PUPCAL

This program uses two transient recorders. One transient recorder uses a capacitive divider to measure the voltage applied to the neutron generator power supply, while the other transient recorder reads the voltage at the neutron generator voltage pick-up plate (PUP). The program then calculates the correct value of the capacitor to use with the PUP to make a calibrated capacity divider.

C. BIOTST

This program is used to test the Model 8100 transient recorder for normal operation.

D. BARUM

This program calculates the radioactive decay of the barium bolt used to calibrate the neutron detector and prints a listing with dates and the calibration factor for each date.

VII. DATA STORAGE AND ANALYSIS

Each waveform from the digitizer contains a maximum of 100 words in the identification record and 1000 amplitude values. The 1000 amplitude values are 4-character integers packed into 10-character words for convenience in converting to the format used on the CDC 6600. The 100-word ID is blank-filled on the CDC 6600 using the Fortran format conversion program if there are fewer than 100 words from the digitizer. The data records are read by the CDC 6600 and shifting and masking operations are used to pack the 1000 amplitudes into a 200-word record in octal format. There is no EOR between the ID record and the data records but there is between each 300-word record which represents one waveform. As the waveforms are transferred to the tape, which is stored in the CDC 6600 library (master tape), a sequence number is put into word 100 of the ID record. Since the sequence numbers are consecutive from the beginning of the master tape, the records are counted on the master tape as it is positioned to receive more waveforms. The end of the master tape is located by reading the trailer which is a record containing 10 words of 10HFFFFFFFF. This method of packing the data allows 6000 digitized waveforms to be stored on one 2400-foot seven-track tape. Microfiche of all added waveforms is generated as part of the format conversion program.

Figure 6 is a listing of the ID record. The first 52 words are reserved for possible future use. Most BASIC programs used for testing neutron generators automatically input all of the ID information required except for the serial number of the unit (word 52), date code (word 54), temperature of the unit when tested (word 56), and failure mode, if any (word 64). There is no attempt to use the computer to check for unit failure on explosive neutron generators since there is time for the computer operator to check the transient recorder

Figure 6

Digitized Data Format, CDC 6600

ID record is 100 words, format A10, blank filled.

<u>Word</u>		<u>Contents</u>
PDP-11	CDC 6600	
	1-52	Open (Start at 1 if used)
0	53	Unit type, format (Assignments are made as appropriate)
1	54	S/N, either GBV 123456 or GBV123456
2	55	Date Code, as A70, L71, etc.
3	56	Temperature, Kelvin, Ambient = 293 X (units). Tube test code.
4	57	Shot Number
5	58	Test Location, A2TST or GEND1
6	59	Date, Day-Month-Year as 03-Sep-76 The abbreviation for month is the first 3 letters of the month.
7	60	Waveform, SIG 1 (Arbitrary assignments are made according to the test being conducted) SIG 9
8	61	Bias, time of first digitized sample from FIDU. Must be F format as 43.67.
9	62	Deltat, time interval between data points. Normal .02.
10	63	Sensitivity, must be F format.
11	64	Failure, choices are NONE, EFAIL, HVB, FAIL.
12-13	65-66	Program version, Format is: RTJ D160D, V D4/13/76.
14	67	Probe factor, low voltage, GEND.

Figure 6 (cont.)

<u>Word</u>		<u>Contents</u>
PDP-11	CDC 6600	
15	68	N or blank.
16	69	PFN voltage, units. Tube voltage levels.
17	70	Special use or blank.
18	71	GENO integrator constant.
19	72	Tube S/N, 7-digit number.
20	73	Comment
21	74	TTA number
22	75	Relay closure time and voltage. GENO.
23	76	Cycle number as B/W 62-CY-4.
24	77	Scaler Cal
25	78	Integrator CAL, GENO
26	79	Scaler count.
	80	
	85	
	86	GENO Chassis Measurements
	99	
	100	Sequence No. 14, blank filled, right justified
	as	34
		234
		1234

display of each waveform for an indication of unit failure. It is difficult to define other than catastrophic failures with a computer program; but when testing electronic units with no operator in attendance, the program checks for a neutron output below a preset level. If it finds a low output, the program halts testing and rings the terminal bell several times to call the operator to decide if the test should be terminated.

Several words (58, 67, 71, 75, and 80-99) make references to GEND. Format compatibility is maintained between the GEND SE1065 development neutron generator tester and the Division 2351 digitizer. All words that are in common are assigned to the same words, and GEND requirements that are not used at SLA are assigned reserved locations. The information in words 61, 62, and 63 are used with the stored amplitude integers to reconstruct the waveform for display or analysis using the program UNPACK.

UNPACK is included as a subroutine in any program using the digitized data. The ID record is not affected by either PACK or UNPACK. The time-amplitude data is put into a 2000 word array with alternate values of time and amplitude in appropriate units.

The following are several examples of the output of programs using digitized neutron waveforms from a GE U8261 suitcase neutron generator.

A. Microfiche

Figure 7 is a reproduction of a single microfiche frame labeled with selected words of the ID record. The fiche are generated by the program to convert data from the digitizer to CDC 6600 format. The fiche is delivered to the person responsible for the neutron generator tested. There may be as many as 270 waveforms per fiche.

MICROFICHE FRAME

Figure 7

B. Plot of Maximum, Minimum, and Average

Figure 8 illustrates the output of a program which provides a plot containing a waveform generated by selecting the highest amplitude value of several waveforms at each time increment, a similar waveform containing the minimum value at each time increment, and a waveform generated from the average of all data points at each time increment. The sequence number, S/N, shot number, date, and type for each waveform used in the plot are printed in a table as part of the output. Figure 9 is the output from a variation of this program which plots average, +3 sigma, and -3 sigma.

PLOT OF MAXIMUM, MINIMUM, AND AVERAGE

Figure 8

PLOT OF +3 SIGMA, -3 SIGMA, AND AVERAGE

Figure 9

C. Theoretical Neutron Plot

Theoretical neutron waveforms can be generated from actual voltage and tube current waveforms. Corrections for secondary electron emission in the tube current, pick-up plate calibration variation with temperature, and charging current are made. The charging current, which appears as a non-real part of the tube current, was subtracted using a digitized waveform from a special tubeless unit built for that purpose. A look-up table, which is part of the program, is used to determine what the neutron output should be at a given tube current and accelerating voltage. Comparison can then be made between actual and theoretical neutron output. A variation of this program permits the tube current to be entered by data cards so that theoretical neutron waveforms may be plotted using arbitrary tube currents.

D. Voltage-Current Plot

Figure 10 is a three dimensional plot used to show the relationship among voltage, current, and time during a pulse. An area on the plot can be defined which denotes acceptable operating conditions.

E. Transformer Modeling

The SCEPTRE circuit analysis program has been used to model transformers suitable for neutron generator applications.⁽³⁾ The SCEPTRE results have been compared with digitized data of the actual transformer. Core saturation effects were included in this model. Figures 11 and 12 are views of the digitized data and the SCEPTRE model with two different voltages applied to the transformer primary.

PLOT OF VOLTAGE AND CURRENT TO DETERMINE OPERATING CONDITIONS

Figure 10

IR4 is the current through a small resistor in series with the transformer primary, while VRLD is the voltage across a load resistor across the transformer secondary. Circles are used to represent digitized data from the actual transformer, while triangles are used to represent the SCEPTRE output.

F. Pulse Width Distribution

Figure 13 is a histogram of the distribution of the pulse widths of 701 waveforms from an experimental pulse-forming network.

G. Neutron Detector Tail-Off

The neutron detector scintillator has an afterglow which causes a contribution to the neutron waveform which doesn't represent neutrons. Figure 14B is the output of a program to remove this non-real contribution, while 14A is the uncorrected waveform.

Figure 11A

Figure 11B

Figure 12A

Figure 12B

PULSE WIDTH DISTRIBUTION

Figure 13

OUTPUT WAVEFORM, TRAIL REMOVED.
 SER. NUM. TEST DATE 11-19-77 PLOT DATE 77/10/31.
 TEMP. ACC VOLTAGE 3 TEST NO. 7

Figure 14A

OUTPUT WAVEFORM, WITH TRAIL.
 SER. NUM. TEST DATE 11-19-77 PLOT DATE 77/10/31.
 TEMP. ACC VOLTAGE 3 TEST NO. 7

Figure 14B

NEUTRON DETECTOR TAIL-OFF

VIII. PROBLEMS

Some problems with the digitizing system are described in this section as an aid to anyone interested in developing a digitizing system and to illustrate some limitations of the digitizer. Filtering the digitized data has remained controversial with some engineers who are responsible for a particular neutron generator program not concerned with filtering and others wishing to do any modifications to their data themselves. The transient recorder induced noise and the effect of a software filter are illustrated in Figure 15. Figure 15A is an oscilloscope photograph of a 1 MHz signal applied to the transient recorder input. Figure 15B is the 1 MHz sine wave displayed by the transient recorder's analog output which uses a smoothing digital-to-analog converter. Figure 15C is a display of the unfiltered digitized data, while Figure 15D is a display of the digitized data after the data set has been passed twice through a software four-pole low-pass Butterworth filter. The first pass is in normal time sequence, and the second pass is in reverse time sequence. This results in a cutoff frequency of 2.85 MHz assuming a sample interval of 20 ns. This filter is in assembly language but could be easily converted to Fortran and the filtering done on the CDC 6600⁽²⁾.

Another problem occurred due to the fact that the format of the sensitivities for the various waveforms must be known to be read into the CDC 6600 using Fortran, but under PDP 11 BASIC the number may be in integer, F or E format depending on the value of the number. A program was written in BASIC to assure that the sensitivity would always go onto the tape in F format. The BASIC string functions POS, LEN, and SEG were used to convert integer and E format to F format.

1 MHz INPUT SIGNAL

Figure 15A

OUTPUT FROM THE TRANSIENT RECORDER DIGITAL-TO-ANALOG CONVERTER

Figure 15B

UNFILTERED DIGITIZED DATA

Figure 15C

FILTERED DIGITIZED DATA

Figure 15D

Editing the tapes to eliminate errors is a continuing problem. Minimizing operator input and programmed error checks have reduced errors, but they still occur due to operator error, such as entering the neutron probe factor incorrectly, or equipment failure, such as a fatal mag tape error which terminates the data tape unpredictably. All editing is done on the CDC 6600 using various programs which change the ID record word to the correct value. Since the sensitivities are in the ID record, the data records don't require any modification. The sequence number in word 100, the name of the word to be changed, and the new value of the word are the usual data cards for the edit program. A name such as sens, bias, S/N, etc., is used for convenience instead of the ID record word number.

A recent problem is the large number of waveforms from the GEND SE1065. In 1977, 35,000 waveforms were generated and stored. With normal editing, much time is taken up just storing these waveforms.

Although it isn't a current problem, the assembly language programming required for the drivers is too slow and expensive. With the present version of BASIC, it appears that much of the assembly language could be replaced by BASIC. The earlier versions of BASIC originally used with the digitizer were not versatile enough to replace the assembly language.

IX. SUMMARY

Overall experience with the digitizing system has been good with several thousand waveforms now stored in the CDC 6600 library and a lot of useful analysis done. The computer has proven to be a valuable tool as an aid to the operation of the test site, and more extensive use of it will certainly be done. Reliability of the digitizer has been very good. All DEC equipment is under a maintenance contract. The Biomation Model 8100s are repaired on site if the problem is simple and returned to Biomation if they can't be readily repaired. Spare printed circuit boards for the transient recorders are kept for this purpose.

If a system were to be designed today, other approaches to digitizing would have to be evaluated; but if six to eight channels of digitized data were required with 1,000 data points at a rate of 20 ns, the system discussed in this report would still be competitive.

X. REFERENCES

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