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STATS - A UNIQUE HIGH SPEED, MULTIPLE CHANNEL, REAL-TIME DATA ACQUISITION SYSTEM

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ABSTRACT

A Stand Alone Test System, called STATS, has been developed to acquire and analyze data from as many as 120 analog channels. STATS is used in testing weapon systems under simulated environments at a laboratory in Texas. Some analog channels are sampled every 10 microseconds but most are digitized every 100 microseconds. STATS features hardware data compression and a first-in-first-out buffer for each channel. It has also provided a way for the test configuration to be controlled by the diskette files which contain the test specifications. The analysis specifications are also predefined in diskette files keyed to the particular test type. The techniques used are applicable when: (1) many channels must be monitored simultaneously, (2) channel activity comes in spurts separated by long quiet periods, and (3) more than a few channels experience nearly simultaneous bursts of activity.

Sandia National Laboratories is under the direction of the Department of Energy. Sandia is primarily responsible for the development of weapon systems and energy research. Within the Quality Assurance Systems Evaluation Department, the Systems Test Equipment Design Division is responsible for the design of weapon system test equipment. These testers help ascertain the quality of the weapon stockpile. During system testing, the weapon system is exercised by the System Test Equipment. The tester provides the environments to enable the weapon system to function. This tester also contains the necessary transducers to monitor the weapon under test. The test ascertains that the weapon system did operate per design intent and that it would have worked during actual use.

HARDWARE

Design Requirements

The Data Acquisition System required as a subsystem of the System Test Equipment needs to provide three functions: (1) to signal prestart readiness of both the Data Acquisition System and of the weapon being tested, (2) to record, and (3) to analyze test data.

This test data is of three classes: (1) analog signals; (2) event times; and (3) digitized, recorded parameter values. The function of the Data Acquisition System is to record and interpret test data with respect to the formal objectives of the weapon system test. These objectives are: (1) determination of overall weapon system functional success or failure, (2) determination of functional success or failure of weapon components, and (3) verification of proper tester performance. To establish that these objectives have been met, specific positive criteria, involving time relationships between signals and signal magnitudes, must be satisfied. In addition to these positive criteria, discrepant signal behavior must be detected, if it occurs. It is necessary, therefore, to continuously monitor all analog signals to provide information for determination and diagnosis of any abnormal weapon or tester function. In addition, the Data Acquisition System should also quantize specific measurements, couched in sentence statements which identify the measurement and its engineering units. It should also have the capability to provide a plot of all data for anomaly evaluation if required. Furthermore, it should provide data in a format and output medium compatible with general computers for trend analysis of the weapon stockpile.

Acquisition Requirements

In order to furnish a Data Acquisition System to provide these functions, a unique high-speed, multiple-channel, real-time system was designed. This system is a stand alone system, called STATS (Stand Alone Test System), that can be moved from one test system to another and be configured within two hours for use on the new system. To provide this flexibility, the system was designed with multiple channels of data acquisition. It has a capability of monitoring 120 analog data channels and 96 digital or bi-level channels. Each channel may operate at a sampling rate of 10 or 100 kHz. Because of the number of channels and the required sampling speed, the data rate was greater than the capabilities of conventional multiplexed data acquisition and storage media. It became apparent that some method for monitoring each channel separately and a capability of real-time data compression was needed. Real-time data compression means ignoring each sample which is not significantly different in amplitude from the last saved sample. Therefore, STATS incorporates a modular printed wiring board consisting of a sample and hold amplifier, an Analog to Digital Converter, a real-time hardware data compressor, a first-in-

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first-out memory (FIFO), and required control circuitry for each channel of data. The use of 12-bit A/D converters with 4 and 30 microsecond acquisition times were required to give the needed accuracy, resolution, and sampling rate. The need for real-time data compression required that some capability be provided to record the time of occurrence of each sample. This time requirement and the total test time of 20 minutes necessitated the capability of counting and recording 27 bits of time data. This capability, plus the 12-bit A/D resolution, required a first-in-first-out buffer memory of 39 bits. These 39 bits, plus 7 bits to identify the channel being recorded, required a 46-bit interface to the computer. Three 16-bit interface cards are used. The remaining two bits were used to provide a Data Ready Flag to the computer and a flag that provides an indication that the FIFO memory on a data board is one-quarter full. Since the incoming test signals are not multiplexed, some type of multiplexing had to be implemented to enable the computer to record the data from each channel. This was accomplished by utilizing Tri-State buffers. The third state, a very high impedance state, afforded the capability of connecting 128 channels together, in parallel. It enables the computer to select any channel separately. The Data Ready Flag is used by the software when choosing to store a three-word reading or to move on to the next channel.

FIFO Memory Requirement

Some concern on the capability of the computer to be able to keep up with the amount of data remained, even with real-time data compression. This concern was lessened by the use of the FIFO memories on the data boards. The FIFO (first-in-first-out) memory consists of thirty-nine 4096-bit static memory chips with read and write counters for addressing. When these counters are equal, the memory is empty. Full occurs when a difference of 4095 exists between the counters. The FIFO is also asynchronous; that is, data can be written or read at any given time.

If a FIFO memory becomes full, the sampling rate for the given channel is drastically reduced. Instead of sampling every ten microseconds or even every one hundred microseconds, the rate will typically be about every millisecond. This happens because no writes are permitted while the FIFO is full. Thus, the writing rate becomes the same as the rate at which the channel is being read. (This rate could even fall to zero if the software prevents further reading of this channel.) The effect of this is introduction of aliasing errors and likely misinterpretation of the data.

Therefore, STATS was designed to minimize the chances of any channel FIFO becoming full. The computer interrupt capability was utilized to generate an interrupt when any particular FIFO memory was 3/4 full. This 3/4 interrupt caused the computer to devote full time to acquiring data from this data channel until the 1/4 full flag was sensed. Even with this capability, there might be a time when a particular test signal will provide so much data that the FIFO memory will become completely full. A full flag is used to interrupt the computer. The special attention to that signal is then discontinued. Then the system only takes readings in the normal mode. Later the software notes that the data on this channel has been compromised.

The above design concepts require that several functions be performed. These functions are: channel select and data acquisition, interrupt recognition and control, control of auxiliary oscillograph and magnetic tape recorders, and system calibration. Also, the system has the capability of acquiring digital data from three input ports that are connected to or multiplexed among digital counters, voltmeters, or other digital devices.

Computer Requirements

To accomplish the aforementioned functions, it was apparent that a computer was required. A Digital Equipment Corporation computer was chosen because of the availability of interfacing hardware, software, speed, maintenance, our experience with previous systems, and cost. The computer system is comprised of a PDP 11/34 processor, dual floppy disk, a 2.5-megaword RK05 type disk system, and 2 Expander chassis.

Computer Interface

In order to interface this data acquisition system with the computer, a number of DEC standard interface modules (cards) were used. In total, we used six M105 Address Selectors, three M7821 Interrupt Control Module, seven M1502 Bus Output Interface, nine M1501 Bus Input Interface, three M1500 Bidirectional Bus Interfacing Gates, ten M1801 16-bit Relay Output Interface, four DR11L 2-Word Input UNIBUS Interface, one DR11M 2-Word Output UNIBUS Interface, eight M5864 Optic Isolator, Input, and one M6864 Optic Isolator, Output. The following is a compilation of the function and the hardware utilized.

Channel Control	M1502, M105
Channel Number and Time	M1501
Time	M1501
Time and Amplitude	M1501
Aperture Control	M1502, M105
3/4 Full Identifier	M1501, M7821
Oscillator Control and Handshake	M1502
Full Identifier	M1501, M7821
DC Cal Power Supply Control	DEC KIT 11-H (4 word in, 4 word out with interrupt)
Oscillograph and Magnetic Tape Control	DEC KIT 11-H (4 word in, 4 word out with interrupt)
Interface Status	DEC KIT 11-H (4 word in, 4 word out with interrupt)
DDE and Option Identifier	DEC KIT 11-H (4 word in, 4 word out with interrupt)
Direct Digital Entry (DDE)	8 DR11L's, 8 M5864
Magnetic Tape Control	M1801, M105
Oscillograph Speed Control	M1801
IRIG Tape Search Control	DR11M, M6865
Calibration Relay Control	8 ea M1801

Tester Interface

To interface STATS to the System Test Equipment, considerable hardware and software interlocks have been provided. These include hardware and software indications that the proper number and type of Data Channels (10- or 100-kHz) are configured in the system. Once it has been determined that the Data Acquisition System is configured properly and that the Data Channels are operating satisfactorily and calibrated, a flag is presented to the tester. This flag means the STATS is watching for a START TEST from the tester. When the START TEST signal is seen, STATS begins acquiring data. The tester also provides a "STOP" signal to the Data Acquisition System at the end of the test. This command interrupts the computer, which recognizes that a stop has occurred. The software turns off acquisition, empties all the FIFO memories, reads all digital instruments, and proceeds with an analysis which has been defined long before the test had begun.

SOFTWARE

Selection of RT-11

The software for the STATS was implemented by a team of software specialists from 3 different divisions within Sandia. From early in the development effort, it was decided to use a high-level language as much as possible. The primary reasons for this were to make the programs easy to read, easy to write, somewhat self-documenting, easy to modify, and easy for someone else to maintain for the many years for which the routines may be in use. FORTRAN was picked as the primary language before the final selection of the hardware was made. FORTRAN was known to be available on most minicomputers, plus the software team members were already knowledgeable in FORTRAN. After Digital was selected as the hardware vendor, RT-11 was selected as the operating system to be used. RT-11 provides real-time acquisition capabilities by full access to the I/O page, a simple interrupt scheme, and the extremely helpful FORTRAN callable routines in the System Subroutine Library. RT-11 provides a fast, simple operating system with low overhead. When a real-time test is in progress, no other computer activity is desired which might in any way interfere with the data acquisition. Many tests could not be reproduced if the computer were to fail. With RT-11, it is much easier to determine the state of the machine and the program when a failure occurs than in some more sophisticated operating systems.

Configuration Files

The STATS acquisition software needed to be general purpose in nature, capable of high speed acquisition, instrumentation control, operator interaction, data analysis, and plotting. The system needed a facility to access a unique data base of control information for each test, and yet be controlled by the test equipment and the system operator. STATS must be able to do data acquisition for a wide variety of different tests. In a quality assurance environment, once a test is defined, most of the test parameters will remain the same for each unique system or subsystem subjected to testing. The STATS run-time software is driven by a set of files called the Configuration Files. A set of Configuration Files is created in advance for each type of test required. The Configuration Files contain information regarding which channels are used, the channel speeds (10 microsecond or 100 microsecond), the full-scale input voltage (to determine the gain needed), the aperture required for the hardware data compression, and other miscellaneous control information. If channel 1 will input a signal which will maintain a specified voltage level for a given time, and then drop to 0, this event could be one of the definitions in the analysis file of the Configuration Files. Some test information such as the Test Code and a unique component identification is supplied by the operator at run-time. The Test Code for a given test provides the file name for the Configuration Files. The extension describes the function of the file. The 6 files making up the Configuration Files are as follows.

- TCODE.MAS - contains the master records, header, direct digital entry information, and other miscellaneous flags.
- TCODE.CHN - contains channel information such as channels used, channel speeds, input voltages, and the aperture.
- TCODE.CNM - contains the channel names.
- TCODE.BNM - contains the names of the binary channels.
- TCODE.PNT - contains linearity points information.
- TCODE.ANA - contains the analysis specification.

To make an analogy using car manufacturers, one set of files would be created to test all FORDS and another to test all CHEVY'S. The file names for the FORDS would then be FORDS.MAS, FORDS.CHN, etc. The output files are uniquely identified by test using the test identifier as the extension and an additional character in the file name indicating the file type. For example the raw data file for test number 110 would be named FORDSR.110. The files are gathered on a single platter and later transferred to archive mag tapes on a different computer.

STATS Run Environment

The STATS system is set up with the RT-11 system on one RK05 and a scratch RK05 on the other drive for the data recording. The Configuration Files are on DX0: and some of the auxiliary output files are created on DX1:. The STATS run-time software consists of a dozen or so FORTRAN programs and a MACRO acquisition program. The MACRO program is used only for the data acquisition to get maximum speed. The programs are run in a set sequence by having each program chain to the next program in the sequence passing information such as the Test Code through the chain block.

A Test Run

A STATS run would proceed as follows. The test equipment is attached to the STATS acquisition system. The floppy disk containing the Configuration Files for that particular test is inserted into DX0:. When the operator is ready to run, he runs the program STATS. The first stage of STATS testing is a verification of the configuration information in the Configuration Files checked against the hardware in place. The test will not continue until the required acquisition hardware is properly assembled. When the correct channels and auxiliary equipment are in place, the STATS program chains to the calibration routine. Each channel is calibrated by sending out known voltages from a programmable power supply. Readings are taken and compared to theoretical values. All channels used must pass calibration before the test will continue. Even though a channel is allowed to be within a certain tolerance to pass calibration, information concerning the deviation between the theoretical value and the cal reading is stored and a correction factor is applied to the raw data during the analysis phase.

After all channels have passed calibration, the CAL program chains to the MACRO acquisition program, passing required information through the chain block. A CAL DONE signal is sent from the computer to the test equipment and the acquisition program is ready to take data. Acquisition begins upon receipt of a start-test signal from the test equipment.

The acquisition proceeds with the program addressing each channel in turn. A decision is based on looking at the data ready bit in the individual channel status word. Ready readings are collected and double buffered out to disk. Interrupts alert the program to channels taking data faster than the normal scan can manage. In particular, an interrupt is generated when a board gets 3/4 full, in which case it is given full attention. The program then reads this channel down to 1/4 full and it goes back on the regular scan stack. If a channel were to go full, a full interrupt would be generated and the channel goes back on the regular stack. The channel number and time at which the channel went full is saved to show that overflow has occurred. Timing information has indicated that a full interrupt should only occur if a malfunction of some kind has happened. A stop interrupt from the test equipment ends the test. After the stop interrupt is received, the data channel memories are emptied, all of the data is written to disk and the file is closed. The acquisition program then chains to a FORTRAN program which collects data from optional equipment interfaced through digital input cards. Information concerning which interfaces should be read resides in the Configuration Files.

The Analysis Phase

After all data is collected, the analysis programs are initiated by a chain. One of the Configuration Files drives the FORTRAN analysis program to insure the input data is within predescribed limits. A report is printed indicating how well the components tested performed during the test. If any channel yields questionable results, it can be plotted on the Versatec printer/plotter by a simple program which questions the operator about which channel to plot, the Y axis name and range of interest, and the start and stop times to plot.

Unique Features

We feel that STATS has several features which are unique and of significant value. One important concept is the way in which the analog data channels run independently and are not multiplexed. This allows channels to run at their own rates. A unique feature is the hardware data compression. This allows channels to contribute data only when the signal is showing significant activity. The channel will not be filling the disk with unnecessary data for long periods of inactivity. The Configuration Files provide a method for predefining test parameters in advance of the test. These parameters are only defined once and used over and over for each test. STATS also has a sophisticated method for applying the same analysis limits from the Configuration Files to each unique set of data. A quick plot procedure provides a hard-copy plot of any channel, at any time or on any interval.