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DEVELOPMENT OF A DIGITAL CONTROL SYSTEM FOR A SPACECRAFT PROPULSION TEST FACILITY

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DEVELOPMENT OF A DIGITAL CONTROL SYSTEM FOR A SPACECRAFT PROPULSION TEST FACILITY

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ABSTRACT

A digital computer control and abort system which is used at NASA-Lewis Research Center's Plum Brook Test Facilities is described. The system was designed by NASA personnel to control test operations such as rocket engine testing, structure testing, and wind tunnel tests. Because of the nature of spacecraft system testing, particularly rocket engine testing, the unique features of the system are, control function updating at a 20 millisecond rate, continuous abort monitoring and a software system designed for short duration tests rather than continuous on-line control. To accomplish these system requirements, special hardware was designed. The presentation will include a description of the computer system including special interface hardware as well as a general description of the software used.

INTRODUCTION

Many of you here are involved in propulsion system testing and therefore do recognize the need for an automatic sequence control system. There are many different control systems in commercial use today, however most of these are designed to control industrial type processes, and are not suitable for control of aerospace test facilities. In aerospace test facilities the control system is required not only to control the test article but must also control the test environment. Because of the short duration experimental testing which involves extremely high energy release rates the system must have fast response, high reliability, and be easily adapted to changes in the experimental test programs. The control system must remotely operate many different valves, pumps, motors, and heater circuits. In addition to providing test control the system must also monitor the test and insure that the performance remains within limits. To be effective in an aerospace test facility the system must be made flexible enough to readily accommodate different test programs, but not at the sacrifice of reliability.

My presentation will describe a digital computer control and abort system which has been used very successfully at NASA-Lewis Research Center's Plum Brook test facility. The system was designed to control test operations such as rocket engine testing, vehicle structure testing, and wind tunnel tests.

The computer control system to be described was first used to control a test program in the space simulation chamber. The Spacecraft Propulsion Research Facility (Fig. 1) can provide simulated space exposure and high altitude firing of spacecraft propulsion systems and associated equipment. The vacuum test chamber is 38 feet in diameter and 50 feet high. It has an ultimate clean dry vacuum level of 5×10^{-8} torr. The chamber is equipped with a liquid-nitrogen-cooled heat sink, and with a thermal radiation simulator consisting of quartz infrared lamps which provide a radiant flux of 130 watts per square foot on a test article 22 feet in diameter and 30 feet high. The chamber is vertically oriented within the test building, and is equipped with a hinged top cover 27 feet in diameter to allow for installation of the test article. Test engines are fired downward through a water-cooled stainless steel exhaust diffuser duct 11 feet in diameter and 37 feet long. It has an 11-foot diameter quick opening valve at the lower end of the duct which opens at a maximum rate of .4 sec to 100% open. The duct is contained within, and discharges into a concrete spray chamber which is 67 feet in diameter and 119 feet deep, and contains 1,750,000 gallons of water. Water in the spray chamber can be cooled to 40°F and is circulated through a spray system at 240,000 gallons per minute to provide for cooling of the exhaust duct, exhaust gases, and condensation of water vapor in the exhaust products. Noncondensables are exhausted by means of a three-stage steam ejector system. The exhaust system is capable of handling 100,000 pound thrust hydrogen-oxygen engines at an exhaust diffuser discharge pressure of 1.7 psia.

Currently we are testing a modified Centaur space vehicle with two RL-10 hydrogen-oxygen engines. The purpose of the tests are to increase the vehicle's mission flexibility by providing the capability for a third engine start after a 5½ hour coast to synchronous apogee. This new configured Centaur will be boosted into earth orbit by a Titan vehicle.

The requirements for the sequence and abort system for this test program are to control 47 on-off facility and 20 vehicle functions such as valves, pumps, and heater circuits, to generate 10 marker signals for data recording and to provide changes in setpoints on 4 pressure control systems. The sequence and abort system must monitor for abort purposes, 20 facility and 30 vehicle parameters. Because of extreme fast response of the test program, specifically the RL-10 engine firings, the sequence and abort system must be able to change its output commands at a 20 millisecond rate. It also must monitor the test parameters for abort purposes at a near continuous rate with the capability to arm or disarm individual input parameters at a 20 millisecond rate.

To accomplish the described task we use a Scientific Data Systems 910 computer equipped with standard and special design interface hardware. The standard interface hardware consists of a paper tape reader and punch, card reader, line printer, local and remote typewriter, CRT display, 10 channel D/A and 2 magnetic tape units. The special interfaces were designed and built by NASA personnel. For on-off control of the test operation a special output relay interface was designed, providing the computer with the capability of simultaneously operating any one or all of the 192 relays used in the test sequence. To provide sequence "Holds" for different test events, the computer makes use of a special input interface that allows it to test any one of 24 input signals. To monitor the test operation for abort purposes, the computer uses a special interface referred to as the abort monitor. A block diagram of the Abort Monitor is shown in Figure 2. The Abort Monitor receives its input signals from the test facility in the form of individual parallel analog signal lines. When the signal enters the Abort Monitor, it is compared to a setpoint voltage which represents the abort level. The output from the electronic comparator is a digital "1" for an input signal greater than the setpoint, and a digital "0" for one less than the setpoint. This digital signal is now strobed into a storage register at a 250 KHZ rate, the reason for this "data register" will be explained later. The Abort Monitor contains two other storage registers, the "control register," and the "mask register." The "control register" contains the test requirements in digital form for all abort channels while the "mask register" indicates an armed or disarmed condition for each abort channel, "0" for armed and "1" for disarmed or masked out. The information stored in the "control register" and the "mask register" is changed as required by the computer. The three registers are combined in an exclusive "OR" resulting in an output which is a digital "0" for a go condition and a "1" for an abort condition. When an abort occurs, an interrupt is issued to the computer and the "data register" is frozen, by turning off the 250 KHZ clock to save the input signals and thereby making it possible for the computer to output the cause(s) of the abort on the "CRT," printer, or typewriter. It must be emphasized that the Abort Monitor accepts and compares each abort channel in a parallel rather than a serial or sampled data manner. This comparison is independent of the computer and is continuous and only interrupted for 16 microseconds when the computer changes the "control register" or "mask register." Without this type of abort monitor the speed of our computer would not have been adequate to control this test program.

The proper operation of the computer and abort monitor is assured by a device called a "watchdog timer." The "watchdog timer" receives special signals from the computer and abort monitor at regular intervals. Upon failure of either of these signals it will send an abort interrupt to the computer and will cause a nonsequence shutdown of critical test items.

A computer program to take full advantage of the standard and special interface hardware was written. This program accepts all of the test requirements prior to the start of the test sequence. Information is checked by the computer for format and order, then stored for use during the test automatic sequence. The computer program is started when the facility manual prerun check sheet items are completed and all computer controlled items are switched to the program mode. At this point the computer checks the abort input signals for an initial condition "go," receiving this, the computer gives the test conductor a ready light. Only at this time may the Test Conductor start the test. Upon "start" initiation the computer, following its stored test sequence, changes output relay states and abort monitor "control register" and "mask register" data at the required time during the entire test sequence. If at any time, during the test sequence, an abort interrupt is received from the abort monitor, the computer will immediately stop the run sequence and execute an abort sequence. While performing the abort sequence, the computer reads the frozen data in the abort monitor and outputs the cause of the abort. At the completion of the test sequence the facility is returned to manual control for a manual check sheet clean up and shutdown.

A recent addition to the computer system is a CF-16A mini-computer. This mini-computer is programmed to operate as an abort monitor and can be used, in place of, or with, the hardware abort monitor for slow response input signals. As in the case of the hardware abort monitor, the CF-16A runs independent of the 910 computer comparing input data to the stored limits, and as before, an abort interrupt is sent to the 910 computer if an out of limit condition occurs. The difference in the two techniques is that the CF-16A uses a stored value for the abort limit rather than a setpoint voltage. However, the CF-16A inputs and compares the data by a serial method and therefore is slower than the parallel method used in the hardware abort monitor.

CONCLUSIONS

The sequence and abort system which has been described in this paper has been used very successfully for two years at the Spacecraft Propulsion Research Facility. By changing patchboards and inputting a different set of test requirement cards, it has been used to control hypersonic tunnel tests and will be used for structure testing of the Viking shroud. We have found the system flexible making it possible to change test requirements between passes, thus making it possible to perform many different test sequences during one facility countdown. Testing in this manner, we have reduced test operation manpower, improved test repeatability and have been able to perform more complex test procedures with complete safety.

PLUM BROOK
SPACECRAFT PROPULSION RESEARCH FACILITY

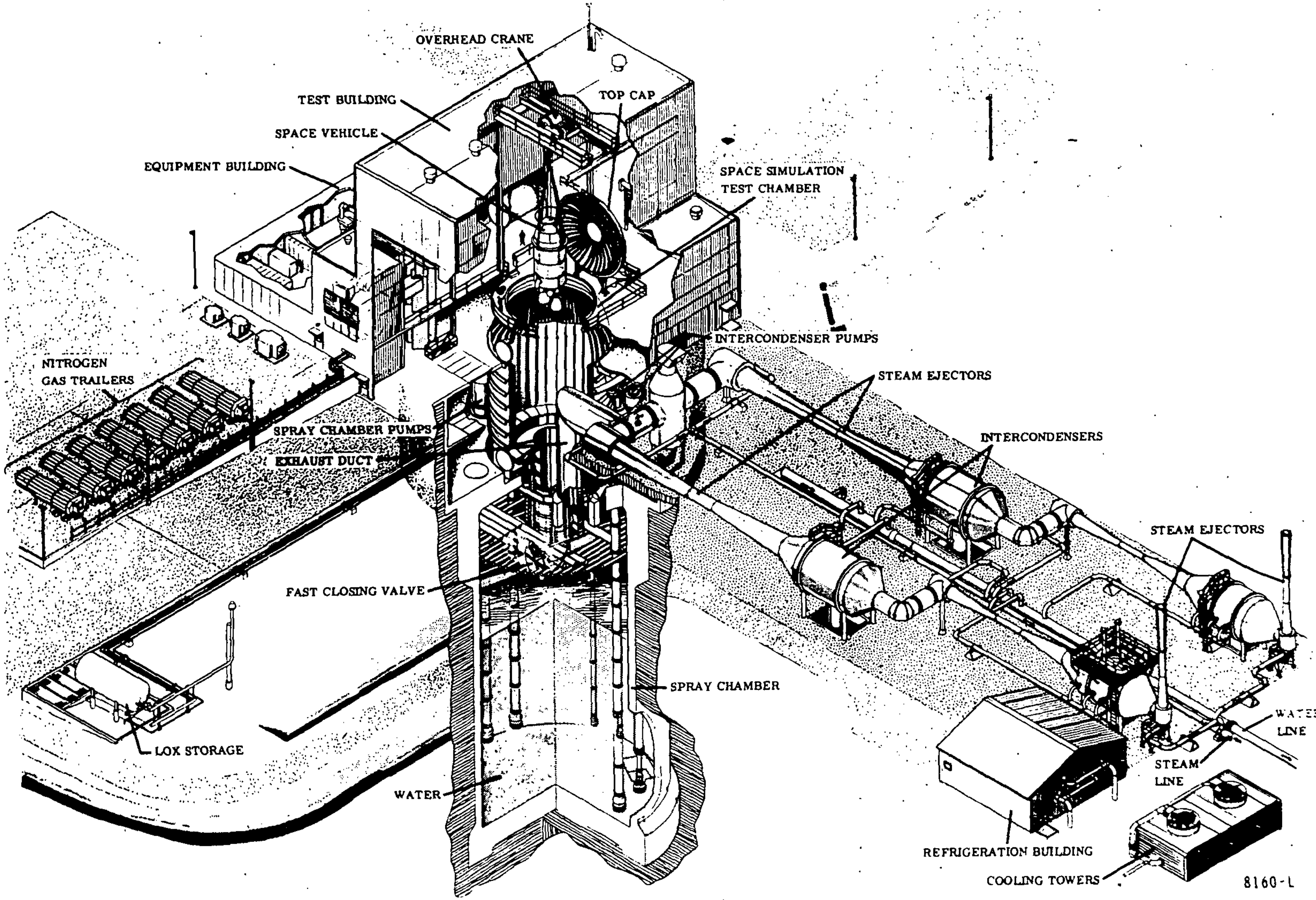

Figure 1

ABORT MONITOR

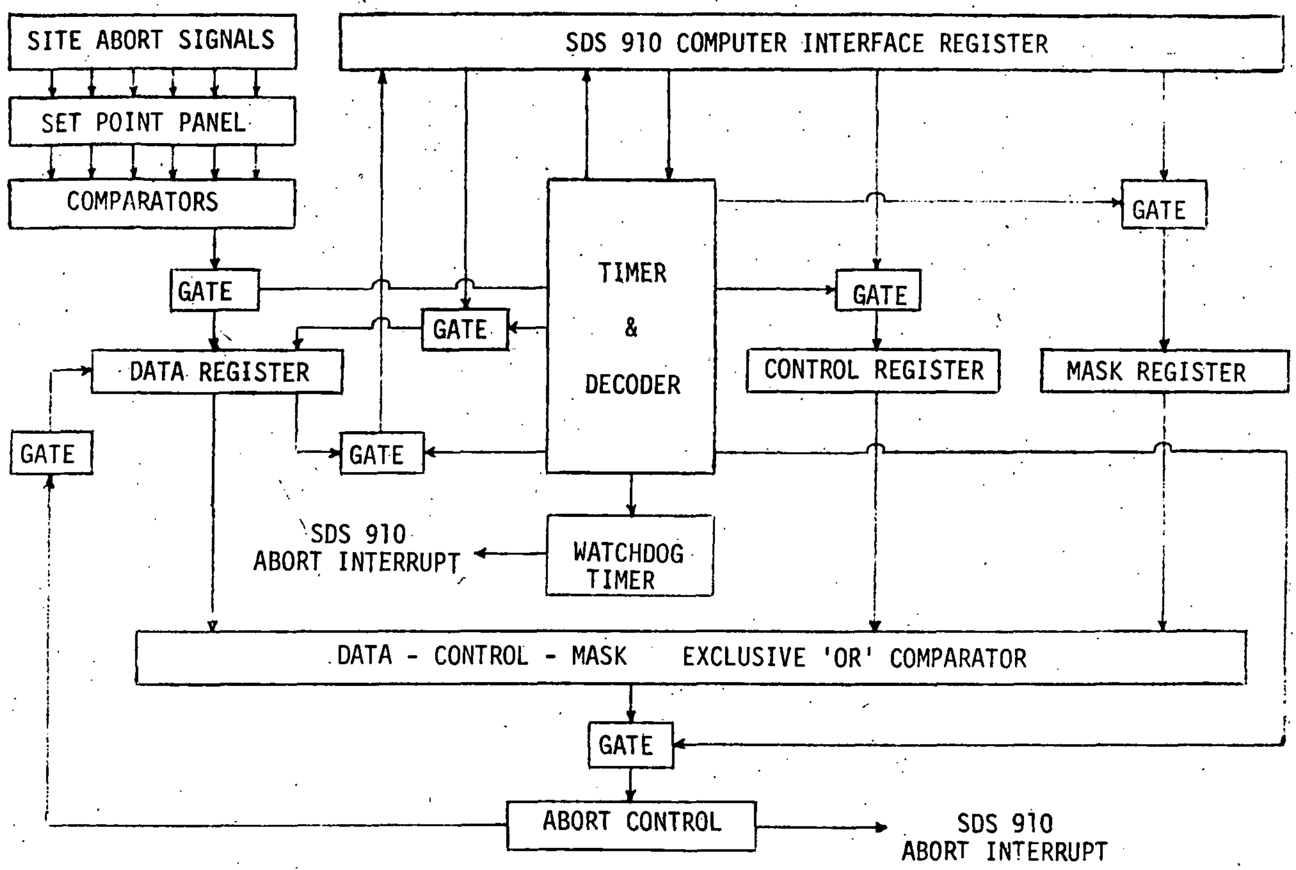

FIGURE 2