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THE TRITIUM SYSTEM TEST ASSEMBLY
CONTROL SYSTEM COST ESTIMATE

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The Tritium Systems Test Assembly (TSTA), is dedicated to the development, demonstration, and interfacing of technologies related to the deuterium-tritium fuel cycle for the fusion reactor systems. Tritium, an isotope of hydrogen, will be a major fuel for fusion reactor systems. The principal objectives for TSTA can be concisely stated:

(1) demonstrate the fuel cycle for fusion power reactors;
(2) develop, test, and qualify equipments for tritium service in the fusion program;
(3) develop and test environmental and personnel protective systems;
(4) provide a final facility that can be used for demonstration and as an example that could be directly copied by industry;
(5) demonstrate long-term relability of components;
(6) demonstrate long-term safe handling of tritium with no major releases or incidents; and
(7) investigate and evaluate a reponse of the fuel cycle and environmental packages to normal, off-normal, and emergency situations.

The TSTA will consist of a large gas loop, Figure 1, which can simulate the proposed fuel cycle for a fusion facility. The loop, as shown, does not include any specific fuel injection system, but will be sufficiently versatile so that such systems can be added as the design requirements are better defined. The gas loop will be designed to handle up to ∿500 moles per day DT. This flow will provide cycle operating experience on a scale that is equal to or greater than the full-scale fuel cycles currently being addressed for TNS and EPR systems. To accomplish this TSTA will require an on-site tritium inventory of approximately 200 g.

The assembly to do this will consist of a number of integrated subsystems as follows:

- Vacuum pumping
- Transfer pumping
- Fuel cleanup (ash and impurity removal)
- Hydrogen isotope separation (cryogenic fractional distillation)
- Fuel mixing and injection (including impurity simulation)
- Interfaces with external systems (neutral beam, coolant breeding blanket systems)
- Fuel storage

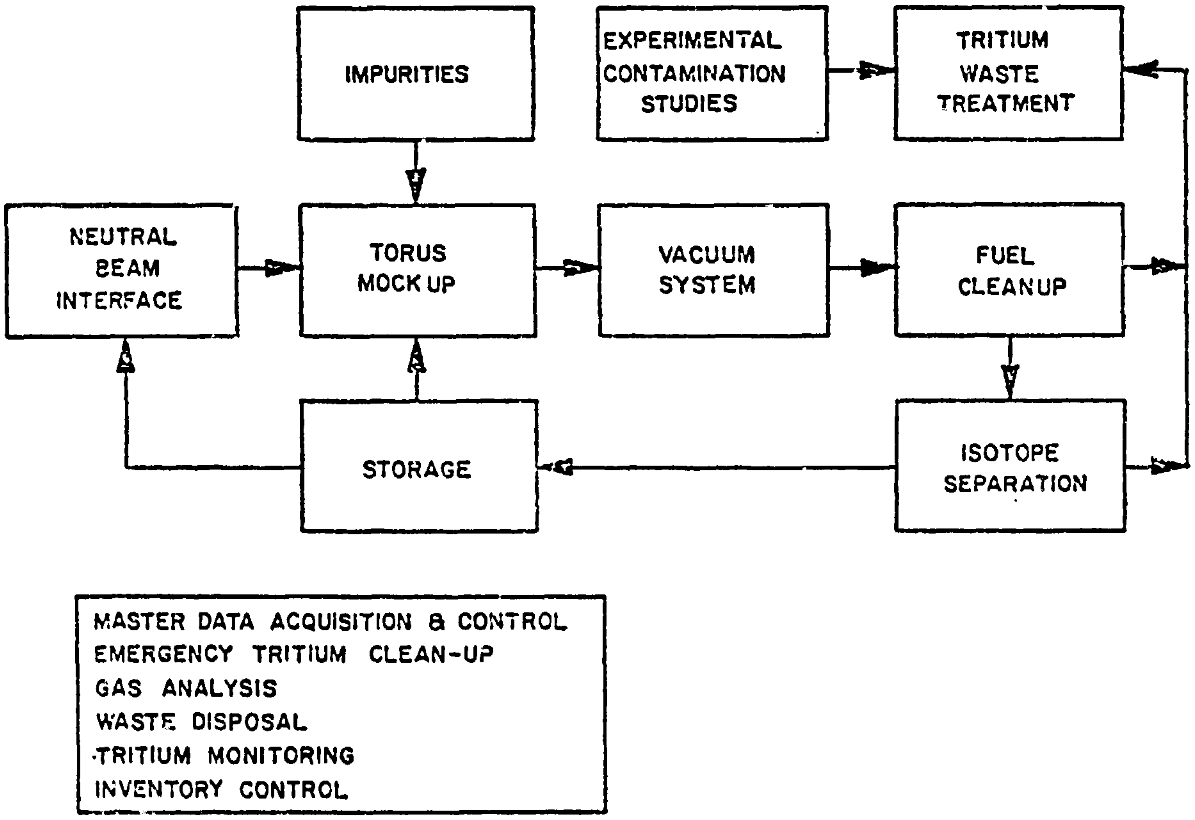

Figure 1, Main process loop and auxiliary systems.

Essential functions associated with the overall assembly must include:

- Tritium waste treatment
- Emergency room cleanup and effluent controls
- Waste disposal
- Radiation monitoring
- Personnel safety
- System maintenance
- Instrumentation
- Computer control and simulation
- Analytical systems (i.e., gas analysis), and
- Quality assurance procedure

The current experience and expertise will be used at TSTA to insure that the design of the facility will reflect the most current information and philosophy pertaining to tritium technology.

While the design of any specific subsystem may not require a significant technology advancement, the integration of all of these subsystems into one package is a significant advance. The flow rate and the total quantity of tritium to be handled in a fusion reactor on a routine basis necessitates the establishment of TSTA as a demonstration facility.

A very significant goal at TSTA will be to demonstrate that large quantities of tritium can be handled safely on a routine basis. The establishment of environmental and safety packages for tritium systems within the Magnetic Fusion Energy (MFE) program will be a significant milestone. The TSTA will serve as a base-line facility that will provide a large data base that can be used to establish future guidelines and requirements for fusion facilities.

It is therefore imperative that TSTA be designed and operated to assure that major releases of tritium to the environment can be avoided, and to demonstrate that significant personnel exposure can be avoided. This in itself is as important as any other objective set for TSTA.

TSTA Overview

TSTA can be broken into four major subdivisions:

(1) the main process system,
(2) the environmental and safety systems,
(3) supporting systems, and
(4) the physical plant.

The main process system is designed to provide a demonstration of all of the components of a deuterium-tritium fuel cycle. These include the mixing of D-T with typical fusion burn impurities in a vacuum, the separation of the deuterium-tritium isotopes by cryogenic distillation, and the fuel cleanup system which will employ a cryogenic freeze technique.

The environmental and safety systems consist of five major subsystems:

(1) Tritium Waste Treatment (TWT)
(2) Emergency Tritium Cleanup (ETC)
(3) Experimental Combination Studies
(4) Tritium Monitoring (TM), and
(5) Secondary Containment (SEC).

The tritium waste treatment system is designed to recover gaseous wastes and absorb them on molecular sieve beds.

In the event of an accidental spill of T_2 into the building, the emergency tritium cleanup system, dedicated to the treatment of room air, is called into use. It will operate on a similar principal to the TWT, but with a flow rate of 1000 cfm. The ETC will be tested by the deliberate release of D_2 containing tracer quantities of T_2.

The experimental contamination studies will be set up in a separate room at TSTA. This portion of TSTA is devoted to deliberate high-level contamination of components and structural materials and a study of cleanup methods, kinetics, etc.

Tritium monitoring instrumentation will be installed throughout the building as well as in effluent streams, stacks, and process lines (as needed).

Secondary containment will be employed wherever a hazardous quantity of tritium is at risk, based on the structural design of the particular subsystem and a risk evaluation.

MDAC Overview

The Master Data Acquisition and Control System (MDAC) will control all functional operation of TSTA. It is designed for redundancy to avoid emergency shutdown in the event of component failure. The MDAC will permit examination of off-normal and emergency operating conditions which will be deliberately demonstrated. It will be equipped with both an uninterruptible power supply and an emergency generator set.

The CAMAC branch couplers will be located in a CAMAC master crate (system crate). This master crate will be interfaced to all four computers in the computer subsystem. A priority arbitration circuit in the master crate allows only one CPU at a time to have control of a CAMAC cycle.

Figure 2 depicts the redundancy of the master crate which contains the interface to the four CPU's and the CAMAC branches. The CAMAC branches will be multiplexed to either of two identical master crates. The four CPU's will be interfaced to both master crates. This configuration permits communications with the facility should a malfunction in either master crate occur. Redundancy is not carried beyond this point in the DAS and PCS subsystem with the exception of some duplications of transducers.

The primary purpose of the Master Data Acquisition and Control System is to accurately measure performance parameters and provide control of components, subassemblies, and the TSTA as a whole; to assure adequate safeguarding and accountability of records of

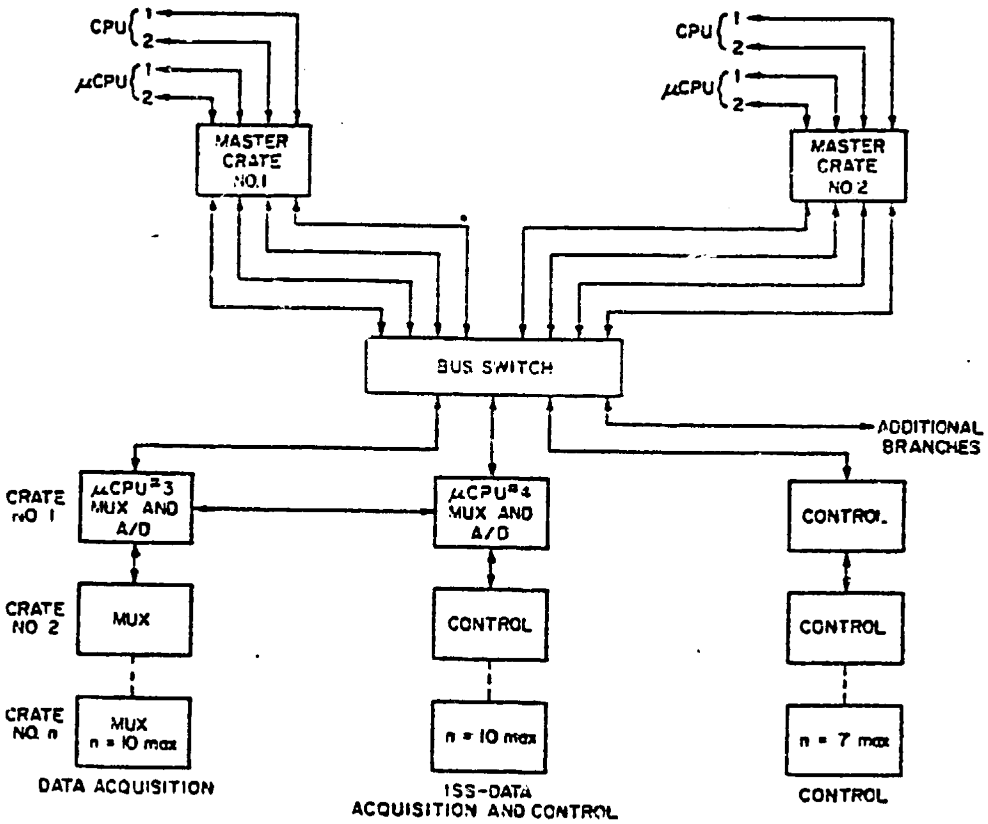

Figure 2, CAMAC Master Crate and CPU Interface

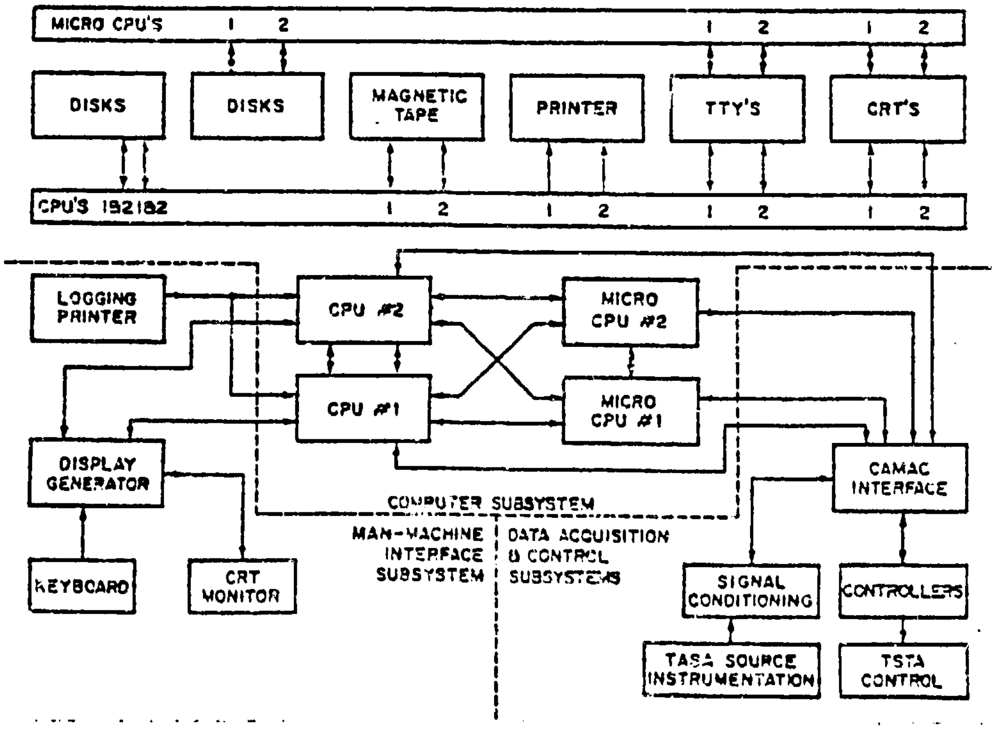

Figure 3, TSTA MDAC Subsystems Interface the large tritium inventory; and provide alarms for "out of limit" processes and conditions.

The Master Data Acquisition and Control System's (MDAC) hardware configuration consists of a Data Acquisition Subsystem (DAS), a Process Control Subsystem (CSS), and Software Subsystem (SSS). A block diagram of the hardware subsystem and the interfaces between them is shown in Figure 3.

The analog signals from the facility shall be brought into the control room and routed to the appropriate signal conditioning/calibration circuit by way of a patchboard system. The signal conditioning section shall condition all signals to plus or minus 5 volts DC full scale and filter them to a bandwitch of 1, 3, or 10 hertz as applicable prior to their being patches to an analog multiplexer and sent to the 12 bit analog to digital converter. This data will be stored in the memory of the microcomputer (Micro CPU-3) which controls this section of the DAS. This data will then be transferred to CPU-1, Central Processing Unit of the computer, or -2 as applicable at a predetermined rate.

The digital signals from the facility shall be brought into the control room and routed to optical or relay signal isolation circuits via a patchboard dedicated for digital signals. The signals will be patched into registers which will be read by Micro CPU-3 and the information passed on to CPU-1 or -2 when a status change is recognized.

The calibration of the DAS Instrumentation channels may be accomplished either under manual or computer control. A single channel may be addressed and calibrated separately or all channels calibrated as required by the operational circumstances. Under normal operational conditions, periodic calibration of all DAS instrumentation channels shall be accomplished under computer control.

The TSTA Computer System (CSS) is designed as a modular redundant system wherein the facility control and data handling functions of the computer and disks can be shared in case of malfunction of any one or more units so that the TSTA system can continue safe operation. This redundant network of CPU's and disks is required for the system to be highly reliable and fault tolerant. A block diagram of the hardware is shown in Figure 4.

Table I indicates the 16 various operating modes for the network of two CPU's and two Micro CPU's ranging from complete normal operation to total loss of computer control. The redundant fault tolerant nature of the TSTA computer system is clearly shown. Ten operating modes represent normal operation of the control and data acquisition functions of the TSTA computer system, five modes require controlled shutdown and one results in total loss of computer control, with manual shutdown required.

The various optional modes are:

A) With the loss of CPU-1, CPU-2 functions as the main control of the TSTA; however, the system operates without the off-line data reduction capability.

B) With CPU-1 operating, loss of CPU-2 is identical to the operation described above.

C) Only in the event of the loss of both large CPU's (CPU-1 and CPU-2), does the system have to be shutdown using Micro CPU-1 or -2. With loss of CPU-1 and CPU-2, the majority of all data recording capabilities are lost.

D) Loss of either of the Micro CPU's (Micro CPU-1 or CPU-2) results in the remaining micro CPU being used for controlled shutdown of TSTA.

E) Loss of both micro CPU's or, a combination of a micro CPU and large CPU, will still result in full control function capabilities and data acquisition functions; however, no off-line data reduction or system studies can be performed. TSTA can operate normally in this mode.

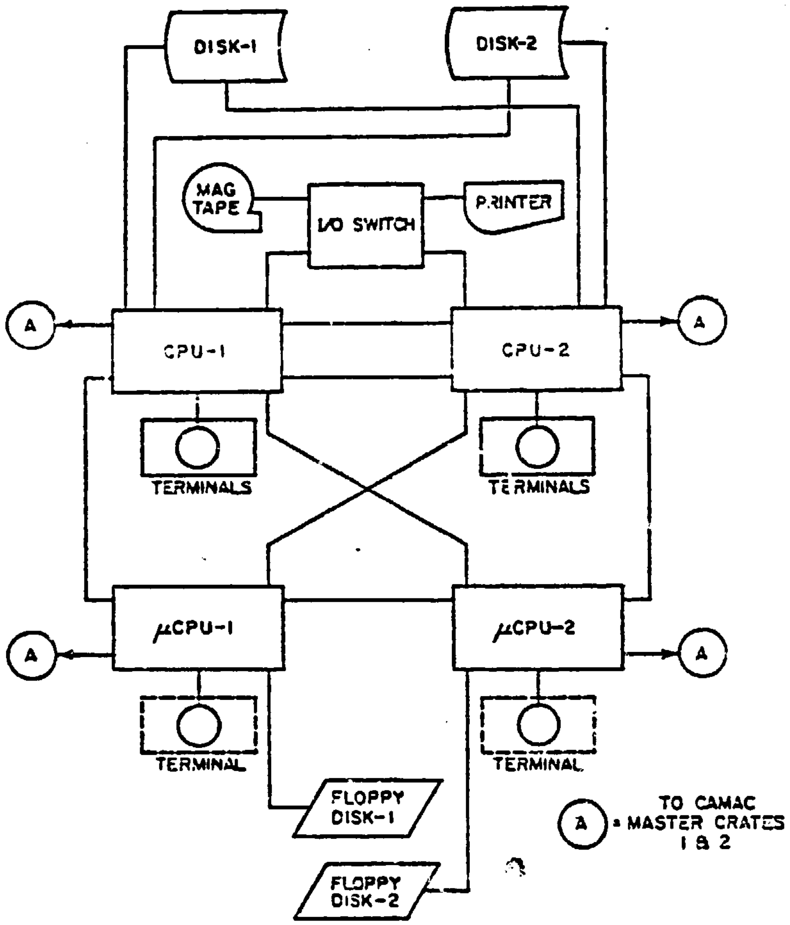

Figure 4, Basic Data Flowpaths for CSS

TABLE I

CPU's DOWN / CPU	NONE	1	2	µ1	µ2	1,µ1	1,µ2	1,2	2,µ1	2,µ2	µ1, µ2	1,2, µ2	1,2, µ2	1,µ1, µ2	2,µ1, µ2	1,2, µ2,µ2
1	C	-	C	C	C	-	-	-	C	C	C	-	-	-	SD	-
2	DR	C	-	DR	DR	C	C	-	-	-	SSD	-	-	SD	-	-
µ1	SSD	SSD	SSD	-	SSD	-	SSD	SD	-	SSD	-	-	SD	-	-	-
µ2	SS	SS	SS	SSD	-	SSD	-	SSD	SSD	-	-	SD	-	-	-	-
OPERATION STATE OF SYSTEM	FN	CN	CN	CN	CN	CN	CN	CSD	CN	CN	CN	CSD	CSD	CSD	CSD	MSD

C - CONTROL & DATA COLLECTION
DR - DATA REDUCTION, SYSTEM STUDIES & SOFTWARE DEVELOPMENT

FM - FULL NORMAL
CN - CONTROL NORMAL
CSD - CONTROLLED SHUTDOWN

F) With the loss of any three CPU's the system must be shut down under controlled procedures.

G) With the loss of all four CPU's the TSTA facility would require manual shutdown.

It is the function of the Data Acquisition and Control Software to gather information that is telemetered from the TSTA and store this information in an orderly fashion. It is the function of this software to transmit control action to various devices in the TSTA in order to allow the operator and various software routines to maintain the desired control over the TSTA. Table II is a summary of Data Acquisition/Control Channels.

The key functions performed by the control software are:

A) Provide a generalized interface with the communication channel.

B) Provide periodic data acquisition based on a predefined scan list (status scanning by exception).

C) Provide for random data scans and for special case application with control of scan priorities).

D) Provide both periodic and random control command checking (check before operating safeguards).

E) Provide data for the data management software.

One key milestone in establishing an instrumentation design is to decide what input interface voltage level to use. This may not seem important at first glance until one realizes that there is a significant amount of DAS hardware affected by the levels chosen. For example, the transducers, signal conditioning amplifiers, multiplexers, and analog-to-digital converter are all affected.

TABLE II

DATA ACQUISITION/CONTROL CHANNEL SUMMARY

TSTA Subsystem	Data Acquisition			Control	
	Analog Chs'	Status Chs'			
		1 Bit	2 Bit	Analog	Digital
Facilities (FAC)	10	62	0	0	0
Vacuum Facility (VAC)	9	20	0	0	20
Fuel Cleanup (FCU)	37	4	4	6	4
Isotope Separation (ISS)	61	2	19	2	19
Transfer Pumping (TPU)	53	0	58	0	58
Impurity Simulation (IMS)	6	4	0	0	0
Fuel Injection (FIJ)					
Neut. Beam Intfce. (NBI)	3	0	0	0	0
Cool. Loop Intfce. (CLI)					
Breed. Blkt. Intfce. (BBI)					
Building Ventil. (VEN)	2	0	7	1	7
Emer. Trit. Cleanup (ETC)	58	40	4	8	4
Trit: Waste Trtmt. (TWT)	4	60	0	0	6
Exper. Contamination Stud. (XCS)					
Waste Disposal (WD					
Tritium Monitor (TM)	12	0	0	0	3
Secondary Containmt. (SEC)					
Master Data Acqu. & Cont. (MDAC)	36	0	12	0	0
Gas Analysis (GAN)	4	0	0	0	1
Uninterrupt. Power Supply (UPS)	6	4	0	0	0
Emergency Generator Set (EGS)	7	3	0	0	0
Inventory Control (INV)	15	0	13	0	13
TOTALS:	323	199	117	17	135

Since many different types of transducers are to be used in the system, it is wise to use a bipolar (plus or minus) input interface. This type of interface avoids forcing an unnecessary limitation on system hardware, a loss of data resolution, and in many cases, a complete loss of data. Some of the transducer types anticipated to be used in the TSTA DAS are notorious for exhibiting anywhere from 0 to 3% full scale (FS) zero shift in either direction (plus or minus) in practice. This action has no effect on a bipolar interface, but in the case of a unipolar interface, data have been lost. This loss will occur with a unipolar interface either at the zero end of the scale when the shift is negative or at the full-scale end if the zero shift is positive. The common way to minimize this data loss is to "Short-Count" the analog-to-digital converter on the lower and upper end of a count used for full-scale so that the converter will actually read a little bit negative and a little over full-scale. This technique is commonly employed to conserve transmitted bandwidth in airborne applications and causes a loss in data resolution equal to the amount of short-count employed. This means if the short-count is 2% FS below zero and 2% FS above full-scale, 4% FS data resolution is lost. This is an unnecessary limitation on hardware and data users for the TSTA application. Bipolar interface removes any necessity of short counting, hardware costs are no greater, it is easy to implement, and it causes no problem in software (unipolar interfaces cause digital-to-analog converter (DAC) changes and software gymnastics to get at the data). Any input sources to the DAS that are negative do not require inverting if a bipolar interface is used which increases system reliability by not incorporating another link in the chain that can fail.

The greatest drawbacks to using a unipolar input interface result from the introduction of the "short-count" to the analog-to-digital converter. This feature makes the system very hard to use. Any checkout or trouble shooting operations require one to mentally convert the short count from binary displays (lights). This operation is very cumbersome and causes considerable errors in manual data translations. Another drawback to a short-count technique is the software used for data processing requires the main processor to keep its own count so it has the correct reference for its arithmetic iterations and output section.

In other words, the software has to be constructed such that the central processor is "fooled" into thinking there is no short count. All processor functions have to be referenced on every iteration. This is not difficult but it adds to the programming and adds processor time.

The TSTA DAS will be designed to facilitate a common interface of plus and minus 5 VDC full scale for all analog and digital parameters. The DAC will be designed for plus or minus 5.12 VDC full scale.

One of the most reliable and economical means of assuring acquisition and preservation of any test data is to multiplex, convert the multiplex data to a suitable form and immediately transfer the data to the computer where the test data may be operated upon, manipulated, and processed prior to being recorded. Therefore, the TSTA DAS will use time division multiplexing (TDM) to acquire TSTA performance and control parameters.

One of the biggest sources of error in a TDM system is called "aliasing." It is a direct result of sampling a continuous function that has signal energy at frequencies higher than twice the sampling rate.

The sampling theorem stipulates that if the rms spectrum of a time function g(t), is identically zero at all frequencies above W Hz, then g(t) is uniquely determined by giving its ordinates at a series of points spaced 1/2 W seconds apart, the series extending throughout the time domain. However, this theorem necessitates that a perfect filter be applied to the signal of interest with a cutoff at W Hz or, the signal spectrum being sampled be perfect with no energy above W Hz. Neither case is practical which then requires the sampling rate to be greater than 2 W samples per second to prevent the aliasing error, which is present in all sampling data systems, from being exceptionally large.

Another major interface to consider is the interface between the DAS and the computer subsystem (CSS). The requirement for a flexible and expandable MDAC precipitates the need for a modular approach to the DAS/CSS interface. The digital interface should be computer independent allowing the CSS hardware to be flexible. The bit throughout rate should be sufficient to accommodate the present and future data rates of the TSTA. One interface system which meets the above requirements is the CAMAC system. The DAS will incorporate the CAMAC standard as it is a modular instrumentation and digital interfacing standard that is particularly appropriate for computer oriented data acquisition and control systems.

The TSTA control system could use an analog system or digital system, but in view of the need for flexibility, speed, and reduced probability of error, a digital computer control system will be implemented. A digital computer system provides for greater growth, more flexibility in control interface, and ease of handling and storing large amounts of data.

Each channel of the MDAC shall be calibrated under computer control at periodic intervals to help assure the acquisition of valid data from TSTA. The minimum accuracy of the calibration circuits in the MDAC shall be a factor of ten better than the end-to-end accuracy of the channel being calibrated. The calibration of each transducer shall be traceable to the National Bureau of Standards.

The 12 bit analog to digital converter allows a resolution of 2.50 mv for a full scale value of 5.12 vdc. In percent of full scale, this value of resolution is 0.05 percent. This resolution is adequate to furnish an acceptable data base for TSTA or, to use as a control input.

Each group of 128 channels will be capable of being multiplexed and converted to a 12 bit value at a rate of 20,000 channels per second minimum. The actual sample rate used will be dictated by the application; however, most control functions which are under direct computer control will be sampled four times faster than that required for data acquisition, as is normal for control channels. Control accuracy of most functions interfaced to the MDAC will be a minimum of plus or minus two percent of the set point.

The performance of the MDAC is dependent upon the individual performance of each component in the chain extending from each signal source, through the taperecorder/reproducer.

The review of instruments in general use in power plant control systems as opposed to the highly reliable instruments described here indicates that the hardware costs are no greater for highly reliable instruments. These instruments are easy to implement, cause no additional problems in software (are easier to program), and provide a larger range of response.