CONF-871007--100

UCRL--96655

DE88 011323

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This paper was prepared for submittal to
12th Symposium on Fusion Engineering
Monterey, California
October 12-16, 1987

October 7, 1987

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Abstract

Extensive experience with previous fusion experiments (TFTR, MFTF-B and others) is driving the design of the Instrumentation and Control System (I & C) for the Compact Ignition Tokamak (CIT) to be built at Princeton. The new design will reuse much equipment from TFTR and will be subdivided into six major parts: machine control. machine data acquisition, plasma diagnostic instrument control and instrument data acquisition, the database, shot sequencing and safety interlocks. In a major departure from previous fusion experiment control systems, the CIT machine control system will be a commercial process control system. Since the machine control system will be purchased as a completely functional product, we will be able to concentrate development manpower in plasma diagnostic instrument control, data acquisition, data processing and analysis, and database systems.

We will discuss the issues driving the design, give a design overview and state the requirements upon any prospective commercial process control system.

Introduction

In 1987, a team based at Lawrence Livermore National Laboratory (LLNL) participated in the continuing design of the Instrumentation and Control System (I & C System) for the Compact Ignition Tokamak (CIT). CIT is expected to be built at Princeton Plasma Physics Laboratories (PPPL) in the early 1990s. During the year, CIT continued to be defined, with several alternatives to the original Conceptual Design Report [1] being examined. In spite of this uncertainty, experience with previous fusion experiment control systems has guided and stabilized the design goal for the CIT I & C System. In this paper we describe the overall CIT I & C design and discuss details of the controls portion. Plasma diagnostic instrument data handling, databases and computational support are covered elsewhere [2].

Design Issues

The operation of a large fusion energy experiment places some strong and, at times contradictory demands upon the control and instrumentation system designer. If we proceed from local to global concerns,

a) individual instruments or equipment must be operated locally for test or calibration,

b) subsets of instruments or equipment must be operated together for test, calibration or reduced-scope experiments,

c) all instruments and equipment must be operated in a coordinated experimental sequence, usually called a "shot",

d) immediate calculations and graphics displays must be provided to guide the next experiment operation,

e) longer-term, more complex calculations must be performed to guide longer experimental runs,

f) acquired data and results must be available where they are needed, but especially in an interactive, ad libitum physics calculational environment.

Previous attempts to satisfy these demands (the TFTR CICADA System [3] and the MFTF-B SCDS system [4]) resulted in large systems oriented around locally designed and implemented data bases. The real-time requirements upon both the computer systems and the data base software precluded many of the sophisticated capabilities that are part of a research computer environment. In both systems, when it was a question of operating the experiment to get data or supplying a physics interactive calculational environment, running the experiment won. Because of this, there has been a migration away from such monolithic, single data base systems toward partitioned systems that employ process control systems, popular general-purpose computers and vendor-supported, timesharing operating systems. Such a migration has occurred in the TFTR CICADA system, which now includes a flexible time-sharing data analysis environment [5].

The Doublet III system [6] separates the real-time control and data acquisition subsystem from the DEC-10 time-sharing subsystem (Doublet III is now using DEC VAXes). The MIT TARA experiment exhibits pronounced separation between the control subsystem [7, 8] and the data acquisition subsystem. At TARA, commercial programmable controllers are used for operating the experiment, but are not part of an integrated commercial process control system. An in-house developed CAMAC data acquisition software package [9] is used to acquire and to do initial processing on TARA diagnostics data. A successful application of a commercial process control system is running at the Laser Isotope Separation facility at LLNL. LLNL experience with this application indicated that the use of a commercial system substantially reduced schedule uncertainty while fulfilling the requirements for the experiment. Experience with the TFTR CICADA system led PPPL personnel to recommend that the CIT I & C system be separated into a machine control part and a diagnostics data acquisition and management part [10]. Commercial process control equipment played a substantial role in the PPPL recommendation.

The evolving architecture of choice has three major subsystems: a vendor-supplied process control system to operate the plant and industrial equipment; an instrument and data acquisition system to operate the plasma diagnostics instruments, to acquire and store data, and to do limited immediate data processing and display for experiment guidance; and a standard, general-purpose time-sharing computer system with

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

expanded data base capabilities for extensive data management, numerical analysis and graphics output. Restated briefly, these three subsystems are control, real-time plasma diagnostic instrument data acquisition, and extended data processing.

CIT I & C System Design

While the architecture of choice has three subsystems, the realities of CIT require that we have three additional subsystems visible at the highest design level. Since process control systems usually do not handle very large volumes of data well (such as large blocks of data produced by CAMAC digital data recorders), we put recording of machine subsystem data (as opposed to plasma diagnostic instrument data) in a separate subsystem called "Machine Subsystem Bulk-Data Acquisition". Two other subsystems are too important to ignore even at the highest design level: precision timing (also called "shot synchronization") and safety monitoring (or "central interlocks"). Figure 1 shows a logical diagram of the CIT I & C System. Precision timing and safety monitoring are shown under the aegis of the Machine Control System.

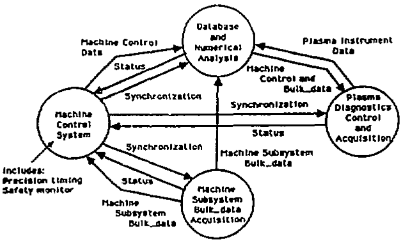

Figure 1. Instrument and Control System logical View

In the sequel, we define in greater detail the following six major parts of the CIT I & C System:

- The machine control system
- The shot (experiment) synchronization system
- Central interlocks, access control and communications
- Machine subsystem bulk-data acquisition
- Plasma diagnostics control and data acquisition
- The central data base, archive and computation facility

The Machine Control System

The machine control system is an integrated process control system such as those provided by Honeywell, Allen-Bradley, Fisher, Measurex or Rexnord. The process control system is hierarchical and consists of a supervisory part and peripheral controllers with varying degrees of intelligence and capability. The process control system connects to controlled machine subsystems through peripheral controllers at Field Termination Units (FTUs). The FTUs and the peripheral controllers may be one and the same thing. The peripheral controllers encompass commercial programmable logic controllers (PLCs) and vendor-proprietary controllers.

High-speed, real-time control systems, such as plasma position control, burn control and pellet injector control are not a part of the "machine control system", although the commercial process control system will provide a supervisory interface to such specialized control systems. Typically, these systems will require real-time sensors and compute power which can best be provided by a dedicated subsystem.

The Shot (Experiment) Synchronization System

All I & C subsystems are required to operate in synchronization with a central timing and shot supervisory control system. We call this the shot synchronization system or SHOTSYNC. SHOTSYNC consists of a supervisory level and the central timing system.

The supervisory level of SHOTSYNC will be implemented as a high level portion of the machine control system. At this level, SHOTSYNC accepts operator input for shot timing, validates and adjusts relative timing among subsystems, sends out coordination commands to subsystems, sets up and triggers the central timing system, and cleans up and terminates the shot sequence. The supervisory level is also structured so that CIT subsystems (subtrees of the timing hierarchy) may be detached and run in subsystem test cycle modes.

The central timing system consists of a master clock and various methods of dividing and distributing clocks and triggers to subsystem hardware. To facilitate a consistent and uniform timebase for interpreting or comparing CIT data, all CIT sampling clocks are required to be phaselocked to the master clock or one of its derivative frequencies.

Central timing system hardware is arranged and connected so that subsystems may be operated in independent test cycle modes. Subtrees of the timing hierarchy may be detached electronically by computer command for local operation.

Central Interlocks, Access Control and Communication

While the actual hardware interlocks required for personnel and equipment safety must operate even if the I & C system is defunct, I & C does provide central overview monitoring and display of interlocks, alarms, fault trips and instrumented personnel exclusion areas. Mimic screen displays, closed-circuit television and intercom are available to assist CIT administration in controlling access to hazardous areas.

Machine Subsystem Bulk-Data Acquisition

In certain machine subsystems, the need to acquire large volumes of data for engineering or scientific purposes will exceed the local data bandwidth of the vendor-supplied control system. These data are typically time-series data acquired in CAMAC digital data recorders or their equivalents and may amount to several megabytes of digital data collected in synchronization with the CIT shot cycle. Data may also be collected for subsystem test cycles that are asynchronous to CIT shot cycles.

Machine data differs from plasma diagnostic instrument data in that the data sources and timing are generally well known and unattended, automatic operation of the data recording equipment can be anticipated.

Plasma Diagnostics Control and Data Acquisition

Plasma diagnostic instruments differ from other CIT machine subsystems in that their requirements and designs are driven by physics concerns that will change during operation as CIT becomes better understood. The need to acquire large volumes of plasma data will exceed the bandwidth capability of the vendor-supplied control system. The control and calibration requirements of the plasma diagnostic instruments will present special problems not ordinarily encountered by process control systems.

The plasma diagnostics data acquisition system consists of computers, software, interfaces, data links and data recorders for controlling plasma diagnostic instruments and for acquiring and storing time-series data produced by plasma diagnostic instruments. For safety reasons, plasma diagnostic instrument vacuum interfaces (e.g. diagnostic instrument port gate valves) may be controlled by the machine control system. To avoid proliferation of different kinds of data acquisition hardware and software, standards for such hardware and software will be developed for plasma diagnostic instruments and will be available for use in other machine subsystems, such as the foregoing machine subsystem bulk-data acquisition.

The Central Database, Archive and Computation Facility

The central database, archive and computation facility consists of computers, mass storage, database manager software, hierarchical storage management software, display and hardcopy subsystems, job management software and physics analysis software. The central database and computation facility will provide services for CIT configuration management, engineering data storage, retrieval and reduction, and scientific data storage, retrieval, reduction and extended processing.

The central database facility and archive provides a uniform method for storing and retrieving machine data, physics data and computational results generated by CIT operation. This is supported by a hierarchical storage manager which controls the balance between on-line and off-line data storage.

Computational services are provided in three environments, all supported by database management: batch, time-sharing and data-driven job dispatch. The data-driven job dispatcher runs jobs based on the availability of incoming data produced by a shot, output-input dependencies and a priority scheme.

CIT I & C System Size Estimate

Control system costs tend to be driven by four relatively simple measures: the number of analog points, the number of digital points, the number of operator stations and the total number of physical display screens. Physics experiments have additional costs associated with high speed digital data recorders, which are reflected in the diagnostic instrument point counts.

An estimate of the expected size (in numbers of instrumented points) was made using the CIT Conceptual Design Report and current data from the TFTR CICADA system. Since re-use of as much TFTR equipment as possible to save costs is contemplated, the inclusion of CICADA data is pertinent. From a recent CICADA point count [11], excluding neutral beams, the point list totals are shown in Table 1.

Table 1. Recent CICADA point count.

	AM	AC	DM	DC	TM	MO	DA	SP
Machine	635	76	6000	1237	336	7	1240	570
Diag.	1014	85	5146	1797	441	36	1136	27
Total	1649	161	11146	3034	777	43	2376	597

Legend:
- AM Analog Monitor
- AC Analog Control
- DM Digital Monitor
- DC Digital Control
- TM Timing
- MO Motor Operator
- DA Time series Data Acquisition
- SP SPecial (IEEE 488, etc.)

Not all the CICADA instruments and controls are required for CIT. In addition, there are new systems on CIT which add points to the CIT estimate. Table 2 shows the summary of carryover points from CICADA and new points for CIT.

Table 2. CICADA carryover plus new point count.

	AM	AC	DM	DC	TM	MO	DA	SP
Machine	422	51	5515	1150	292	6	1190	84
Diag.	379	74	2078	732	293	15	758	27
New Cont.	248	20	650	100	14	36	134	37
Total	1049	45	8243	1982	599	57	2082	148

Legend:
- AM Analog Monitor
- AC Analog Control
- DM Digital Monitor
- DC Digital Control
- TM Timing
- MO Motor Operator
- DA time series Data Acquisition
- SP SPecial (IEEE 488, etc.)

We conclude that the CIT Instrumentation and Control System is comparable in size to the TFTR CICADA system excluding neutral beams. Based upon the number of CIT subsystems to be independently and simultaneously controlled, we estimate the number of operator control stations required to be eight, with 28 physical display screens. The number of mimic panels to be displayed on these screens is expected to be about 400.

We have not addressed the issue of size and capability requirements of other CIT computer systems. It is certain that considerable processing power and data storage capability will be needed, but a much better understanding of the computational requirements for CIT is necessary for a good estimate. A companion paper [2] discusses some of these issues.

Requirements on the Process Control System

The process control system for CIT is expected to be a hierarchial supervisory control system with various tools and utilities to configure it to operate site-specific equipment, to generate operation reports, to troubleshoot, and to interact with external computer systems. In addition, the physical separation of supervisory operator stations from peripheral controllers and Field Termination Units (FTUs) will be required to accommodate the hazardous environment of CIT.

The control system will be sized to handle at least the point counts listed in Table 2, excluding diagnostic points. However, relatively easy and convenient expansion capability must be available in case scientific success dramatically increases the scope of CIT ambitions. Likewise, the operator stations, screen counts and mimic display counts listed in the previous section are required to be supported by the process control system.

A significant and difficult part of specifying the requirements is describing interconnectability of the process control system with other CIT computers and software. The interconnection of the vendor-supplied process control system with other CIT general purpose computers only begins with link-level hardware compatibility. Our specification must address the issues of network protocol, synchronization and compatibility with commercial databases running on the CIT general purpose computers. In particular, many of the process control systems we surveyed have a proprietary distributed database of set points, conversion factors and dynamic system measurements. It must be possible to move such data between the process control system distributed database and a commercial database running on an external computer system. The subset of data to be moved must be easily specifiable, and movement of data between the computer systems must occur in a timely, efficient and automated manner; viz. as a part of a CIT experimental shot.

Implementing the control systems at MFTF-B and TFTR was a lot of work which we hope to avoid with CIT. Manpower required for the process control system will be reduced to procuring it, installing it, integrating it with other CIT computers and configuring it to the actual equipment to be controlled. We will also benefit from the control system vendor's maintenance capability and experience with other, similar installed systems.

The manpower saved by segregating machine control will be applied to efficient reuse of TFTR data acquisition gear, plasma diagnostic instrument data acquisition, data bases for physics data and a physics computational environment which is carefully integrated with CIT experimental operations. These are areas which have no commercial counterparts and where the proposed architecture will permit us to concentrate our efforts with greatest effect.

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