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THE DESIGN OF THE CPRF CONTROL SYSTEM

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Abstract

The Confinement Physics Research Facility (CPRF), currently under construction at Los Alamos, is a facility for research into the plasma confinement properties of various magnetic field configurations. The first device to be tested in the CPRF will be ZTH, a reversed field pinch. The CPRF/ZTH control system has been designed as a distributed system with four major semi-independent subsystems. Each subsystem will be capable of stand-alone operation for purposes of commissioning and maintenance. The subsystem controller hardware has been selected; it will consist of commercially available programmable logic controllers (PLCs) linked by a fast fiber optic network.

The man machine interface, which is under procurement as of June, 1989, will have multiple graphic workstations interfaced to the PLC fiber optic network. The central control console will initially have three stations. Permanent local stations will be located at two of the subsystems with a transportable station serving the remaining subsystems. Standard process control software will be used, but the selection criteria emphasize the open architecture of the system so that user programs can be easily integrated.

System Requirements

The CPRF will occupy four buildings separated from the central control room by 50 to 150 m. A system with distributed I/O, allowing short wiring runs to I/O clusters, seems appropriate. Our experience with centralized control on previous experiments also led us to favor a distributed processor system; operationally one wants subsystem independence so that maintenance, trouble shooting, or upgrades of one subsystem do not affect another. In addition, the various subsystems will come on-line at different times, and it is desirable that the checkout and commissioning of one subsystem not interfere with the development work on another. These requirements suggest a control system that is both physically and logically distributed.

The division into subsystems was made as follows:

- Vacuum Subsystem - This subsystem consists of one roughing and gas fill system and two high vacuum pumping stations. There are approximately 450 signals in this subsystem. Scan rates of at least 2/s are desired.
- Front End Subsystem - This subsystem includes the vacuum liner, shell, and the coil sets. There are about 700 signals, mostly inputs for checking liner temperatures and coolant flow indicators. Scan rates of at least 1/s are desired.
- Generator Subsystem - A 1,430 MVA generator will be used to deliver pulsed power to the facility. Sensors, low level protection, and control logic specifications are being provided by the manufacturer. The control logic will be implemented by Los Alamos using our controllers so that the generator will be fully integrated into the control system. This subsystem has about 350 signals and the desired scan rate is at least 10/s.
- Energy Subsystem - This subsystem consists of the power supplies, capacitor banks, and switching systems that deliver energy to the front end. There are about 1000 signals. The desired scan rate is 10/s for most signals with selected subsets scanned at 20/s and 200/s.

With distributed control, communications becomes very important. A single network to serve both controller-to-controller and controller-to-console messages is desirable. The network must be supported on fiber optic media because of the large, changing magnetic fields in the vicinity of the experiment.

Controller Selection

In 1985 we had begun in-house development of a system to meet the requirements described above. This work, utilizing distributed LSI 11 processors and CAMAC, was reported earlier.[1] A single processor prototype was completed and is being used to operate a small experiment. However, before the system was extended to handle multiple processors needed for a project the size of CPRF, we became aware of the advances that had been made in industrial control systems. After several vendor visits, it was clear that commercially available systems had the capability to handle most of the requirements of fusion experiments.

We developed a functional specification and went out for bids. The bidders list contained both Distributed Control System (DCS) and PLC vendors. The DCS offerings were very attractive, primarily because of their networking capabilities and the level of integration that they offer between the controllers and the console. However, these systems tend to be expensive, generally have slow scan rates when compared to PLCs, and historically have specialized in PID loops, which are of limited interest to us. PLCs, on the other hand, suffer from a lack of integration, limited choice of programing languages, and generally poor programming tools.

In selecting from the many systems available, one must make compromises on cost, programming effort, and performance. In the end, we chose to go with a PLC, the Modicon 984[2] family of controllers.

The 984 is available in a number of processor models, with upward software compatibility between the older and more recent controllers. For our application, the most attractive features were

- the availability of relatively fast controllers. The logic solve speed is 0.75 ms/k.
- fast remote I/O (1.54 Mb/s) with fiber optic links.
- a wide range of I/O modules
- a fast controller network. The speed of Modbus II is 5 Mb/s. Fiber optic support for Modbus II is under development.

[1] P. L. Klingner, S. J. Levings, and R. W. Wilkins, "General distributed control system for fusion experiments," *Rev. Sci. Instrum.* 57 (8), August 1986, pp. 1910-1912.

[2] Modicon 984 is a registered trademark of Modicon, Inc. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof.

- a direct interface from Modbus II to the IBM AT bus which will be used by the console system.
- a new programming package, Modsoft, which supports sequential function chart (SFC) programming as a way to bring some structure to relay ladder logic and includes symbolic references.
- the availability of a Co-Processor module that can be programmed in C and has good access to the PLC memory. This module has an integrated IEEE-488 interface.

Vacuum Subsystem

The controller configuration for the vacuum system is shown in Figure 1.

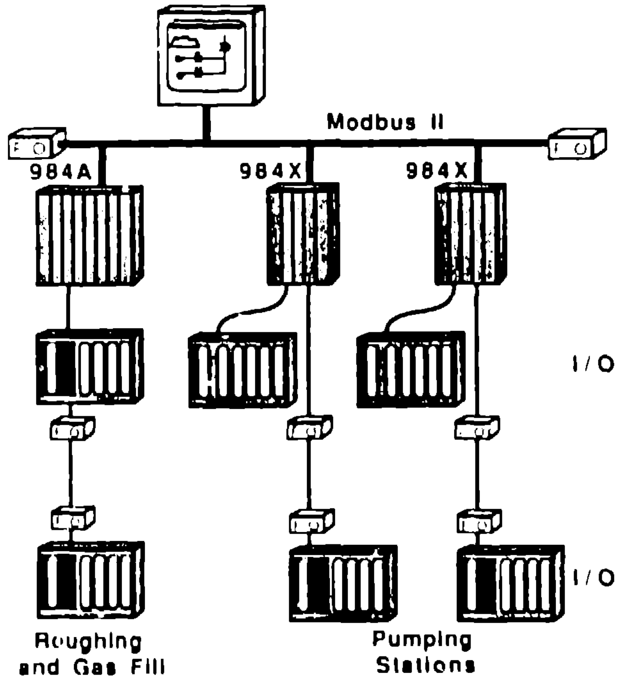

Fig. 1. Vacuum controller configuration

Reliability is a key consideration in the vacuum system. Contamination of the graphite armor must be prevented, and it should be possible to operate with only one pump stand. Rather than specifying a redundant controller, we chose to modularize the control. There are separate controllers for each major component, with identical controllers for each pump stand. Thus, a failure of a pump stand controller affects only that pump stand, and the controller can be easily isolated for repair. It could also be removed to another area as a unit if necessary.

Part of the I/O is located in the Torus Hall, in the same equipment racks as the pump interfaces. These racks float electrically with the pump stands, and are isolated from their controllers by fiber optic remote I/O links.

Generator Subsystem

Figure 2 shows the planned configuration for the the generator controllers.

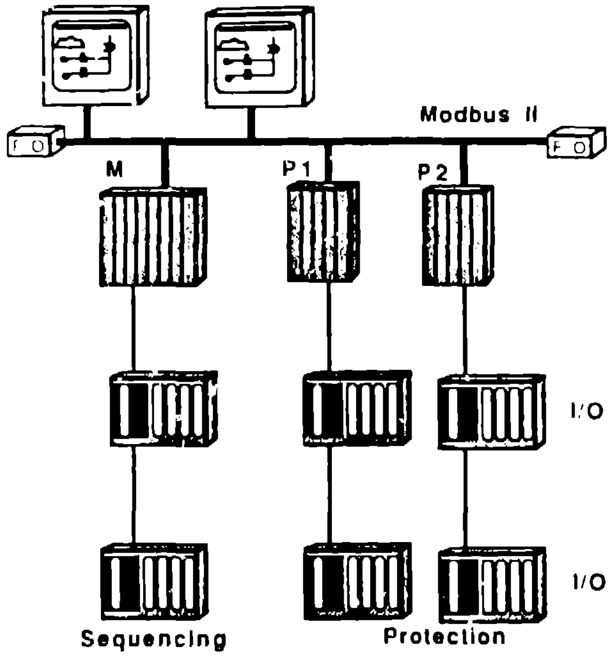

Fig. 2. Generator controller configuration

Again, reliability is achieved by having several small controllers rather than a larger redundant system. Controllers P1 and P2 provide the generator protection. These systems are not identical. Instead, different measurements of critical parameters are divided between the two protection systems so that if one measurement or system fails, the other system will still provide protection. An example is in the lube oil system where there are separate pressure < 60% and pressure < 40% of nominal pressure sensors. The protection logic calls for the < 60% signal to start an A.C. driven auxiliary oil pump immediately and a D.C. driven emergency pump after a time delay of 15 s. The < 40% signal starts the emergency pump with no delay. One signal will go to P1, the other to P2.

The master controller, M, is responsible for the sequencing of the generator and the interaction with the other subsystem controllers but not for any protection functions. This design allows the logic in P1 and P2 to be relatively simple and easy to check. The more complex logic in M can then be developed knowing that the generator protection is in place.

Other Subsystems

The details of the Front End and Energy Subsystems are not known at this time because these systems have not been fully specified. However, the Front End should be relatively simple since it primarily involves slow speed monitoring. The Energy Subsystem will be a more challenging application. Several waveforms will have to be provided to specify desired coil current profiles. We plan to use CAMAC waveform generators driven from an IEEE 488 interface on the Co-Processor for this purpose. In addition, some critical switching must be carried out and confirmed, in a time window of about 50 ms, immediately prior to the plasma discharge.

Console System

Under normal operating conditions all machine control will be carried out from the central control room. The central operator's console will be designed for operation by one person. We anticipate that the console will use multiple IBM 386 (or compatible) computers, one per operator display. The software specifications emphasize incorporation of user developed code into the system and the use of pointing devices such as a mouse or track ball for operator interaction.

Additional local operator stations will be supported. The vacuum system and generator are both high maintenance systems and warrant permanent console installations where operations can be carried out in proximity to the equipment. The other subsystems will be served by a transportable console when required.

It is important that the local consoles operate identically to the central console to minimize software development costs and operator training.

Most third-party console packages that support PLCs have been developed for the IBM PC platform. While vendors are starting to migrate their products to VAX VMS and UNIX platforms, we feel that the best choice today is the IBM 386 or compatibles. These products are fairly stable, and the 386 is likely to retain its lead in price/performance over VMS systems for the near future.

Conclusion

We have chosen an industrial PLC process control system for the control of CPRF/ZTH. The system is distributed, highly modular and provides flexibility through the Co- Processor and its IEEE-488 interface. It has a high speed network that should be adequate for our needs.

The advantages of selecting a commercial system include

- cost savings on system development.
- better documentation than most systems developed in-house.
- less dependence on limited in-house expertise to maintain the system.
- rugged equipment, designed for industrial environments.

We feel that with this system we are prepared to respond to future needs for expansion, increased performance, and additional functionality.

Acknowledgement

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