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Abstract. The COntrol and Data Acquisition System (CODAS) for JET has been fully operational since the first plasma pulse in June 1983. Since then increasing automation of all operations has taken place for both machine control, data acquisition, analysis and display.

This paper gives a brief description of the distributed and hierarchical nature of the system, and then concentrates on its present operation for control of the JET machine.

Keywords. Centralised plant control, Computer organisation, Data acquisition, Direct digital control, Integrated plant control, Multiprocessing systems.

INTRODUCTION

The JET Control and Data Acquisition System comprises an integrated network of minicomputers, microprocessors and dedicated logic. It is used for the control, monitoring, data acquisition, storage, analysis and display for the tokamak itself, its power supplies, auxiliary equipment and diagnostic devices (Fig 2). Norsk Data 16 bit (ND-100) and 32 bit (ND-500) computers are used.

The system is centralised in being operated from a central console under the control of a single computer and for concentration of all relevant experimental results on a single storage and analysis computer. The system is at the same time distributed in a network of many minicomputers, each performing a separate function.

Finally, the system is hierarchical in 3 levels: Supervisor, Subsystem and local unit, and it is in these categories that the hardware and control is described.

An important feature of the system architecture is the concept of a CODAS subsystem. This is a logical grouping of the plant organised such that it can be operated in a meaningful way in isolation from other subsystems for test, commissioning or trouble-shooting purposes. For example, the Poloidal Field subsystem comprises local units of poloidal field coils, coil connection circuit, power supplies and plasma controls. A list of subsystems and local units for the Poloidal Field subsystem and their identifiers is given in Table 1.

TABLE 1

Identifier	Subsystem
MC	Main Console
EC	Experimental Console
CA	Communications Hub
SA	Storage and Analysis
HL	Harwell Link
SS	Safety and Access
GS	General Services
TF	Toroidal Field
PF	Poloidal Field
VC	Vacuum
RF	Radio Frequency
AH	Additional Heating (Neutral Injection)
DA	Diagnostic A
DB	Diagnostic B
DC	Diagnostic C
DD	Diagnostic D
DE	Diagnostic E
DF	Diagnostic F
DG	Diagnostic G
	Local Unit
OH	Ohmic Heating
FGC	Flywheel Generator Converter
COILS	Coil Instrumentation
PV	Poloidal Vertical Field Amplifier
PR	Poloidal Radial Field Amplifier
PPC	Plasma Controls and Protection

DESIGN PRINCIPLES

The conflicting project demands of its research nature and rigid time schedule led to the following criterion for the design of its control system (Bombi, van der Beken, 1984):

- Fully automatic control during normal operation
- Central control and display with flexible and simple user interfaces
- Modularity of function, with independent operation of its subsystems
- Ability to handle large amounts of data (up to 10Mbytes per Pulse every 10 minutes)
- Modularity of components to accommodate future demands and technical developments

With these principles it was possible to assemble the hardware and software for different sections of the plant in parallel, and to commission and operate them independently. At the same time, standard software was developed and tested on a non-sensitive subsystem before installation on all other subsystems. The advantages of this distributed system using similar software are, however, at the cost of the effort needed to install and update the large number of products on the many computers.

HARDWARE

Communication

The subsystem computers are connected in a star arrangement with communication via a hub computer. In fact there are two networks, the second one being for off-line development, although a manual switch selection allows connection of any machine to any hub, and for the interconnection of hubs. This communication is at Level 1 for the highest supervisory functions.

The links used between computers are modified HDLC lines capable of operating at the speed of 1Mbit/s with hardware handshake. The distributed nature of the network is transparent to the user, and although communication for control is minimised by the subsystem structure, extensive use is made of it for displays. This is particularly true on the Main Console where, for example, a user can call an active MIMIC from any computer.

Permanent archiving of experimental data is based on a Mass Storage System connected to an IBM/Cray mainframe computer which also provides off-line data reduction facilities. Copies of all Pulse files are also kept on tapes at JET. The IBM mainframe is sited at the UKAEA establishment, Harwell, some 10km from the JET site. Communication is through a 2Mbit/s British Telecom PCM line and a high speed modem (Jones, 1985).

Interface between the computers and the plant or diagnostic equipment is by CAMAC serial loops to remote CAMAC crates. Each computer drives a separate loop through a serial highway driver board directly plugged into the ND-100 computer bus. Transmission is at 5MHz, bit serial by fibre optics. Two sets of fibre optic cables carrying information in opposite directions are used in a main/back-up loop arrangement. This double loop not only provides redundancy but also diagnostic ability to locate a break by a fold-back configuration at the remote CAMAC interface. This is the Level 2 or subsystem communication.

Level 3 communications are by hardwired connections at the local unit level.

Plant Interface

The CAMAC crates are housed in cubicles built, in accordance with a standard pattern, to suit the requirements of each plant item or diagnostic. In each cubicle plant cables are terminated to a set of terminal blocks, providing a convenient marshalling point, conversion from heavy plant cable to light inter-cubicle wiring and demarcation point. Signals from the plant are routed to Eurocard signal conditioning modules where they are processed before passing to CAMAC modules.

There is a wide range of Eurocard modules, including digital and analog input/output, digital logic functions, optical/electrical conversion and fan-out.

Similarly CAMAC modules allow monitoring, event detection, data-logging and the generation of control signals. A unified software interface, called the equipment drivers, is used by all programs to access signals by symbolic names via standard actions like read, write or initialise (Herzog, 1984). This provides a unified access to widely differing equipment as well as to internally generated software variables and events. The equipment drivers provide checks on access rights, reservation, limits and on the equipment state. Standardisation of access allows complex control tasks to operate without having detailed knowledge of the physical interface. For control, much use is made of a microprocessor module based on the TMS 99000. This is used, for example, to control the main power supplies for plasma control and protection in a variety of ways. These include Direct Digital Control of plasma current, the generation of pre-programmed waveforms, signal analysis and fault protection logic. Increasing use is made of this device as our interlocks and controls become more complex, and hence unsuitable for hardwired devices.

Central Timing System

Synchronisation of the entire JET control system is achieved by a network of optical fibres carrying signals from the Central Timing System. This is essentially a few CAMAC timer modules arranged hierarchically and generating 8 principle timing signals accurate to better than 1us. It is the triggering of these modules that in turn trigger all JET controls and data acquisition and thereby run a JET pulse. This system includes a set of interlocks that inhibit signal transmission at any point during the sequence in such a way that the JET pulse will be terminated coherently.

CONTROL

This maps the hierarchical and distributed arrangement of the hardware in the following 3 levels:

- Level 1: Supervisor (in the MC computer)
- Level 2: Subsystem
- Level 3: Local Unit

Level 1 is the highest supervisory level and runs in the Main Console computer. It contains a Countdown task that issues common commands to all subsystems and checks status returned. In this way all the diverse processes are co-ordinated and synchronised in a standard way, regardless of their different and changing nature.

Level 2 control runs in the subsystem computers. This comprises a supervisor task that responds to Level 1, co-ordinates all actions within that subsystem and reports to the higher level. In addition it includes control tasks specific to the operation of local unit equipment.

Level 3 is the Local Unit level. It includes the CAMAC based controls and dedicated Eurocard logic. The Central Timimg System acts at this level. It is triggered by the Supervisor at the start of a JET pulse.

In addition to these 3 CODAS functions there are 3 other parallel systems for protection and unit control. The first line of defence is obtained by a local set of interlocks built directly into each unit. For example, all power supplies have internal overcurrent protection.

The second line of defence is the Central Interlock and Safety System (CISS), providing essential interlocks between local units. CISS can both prevent operation or force a shutdown of a local unit or subsystem according to pre-defined logic. This system is based on PLCs and designed for simplicity and reliability. It forms a hierarchical structure similar to that for the CODAS minicomputers: there being one PLC per machine control subsystem plus a Supervisor (Fig 2). At present the diagnostic subsystems are not involved in these interlocks.

In the few instances where both the computers and CISS are too slow to react, Direct Safety Systems of hardwired logic provide an immediate response. These include protections for the Poloidal field and Toroidal field coils against short circuits, and the detection of plasma fault conditions.

OPERATION

The integration of all these components is explained by describing the operation of a JET pulse which proceeds as shown in Fig 1 according to the following phases:

- Initial Conditions
- Prepare to Pulse
- Arm
- Pulse
- Post Pulse

Initial Conditions

All necessary power supplies are made available, remote control established for all local units which are put in standby to pulse state. Local alarms are reset and Normal state established for CISS. These are manual operations and only needed at the start of operations or after a major configuration change. The primary user interfaces are active VDU MIMICs for display of plant status and computer controlled touch panels for control. In addition, pre-defined alarm conditions are displayed by an Alarm Package which has sorting and hierarchical display abilities. These interface functions are standard products on all subsystems with individual displays and controls designed for their local units.

Control parameters needed for the pulse are selected. For the primary functions special utilities are provided, and if the JET pulse has been fully pre-defined all parameters can be set automatically by a single operator action.

For the design of plasma profiles, control waveforms are specified in an interactive way with graphical display of the function. Constraints are embodied to ensure limits are not exceeded. Another utility then allows selection from a catalog of pre-defined waves in the form of a menu for rapid definition of pulse controls.

Plasma protection parameters can also be set quickly by a utility that ensures consistency and displays the settings.

Prepare to Pulse

From this point the process becomes automatic with commands issued from the Main Console computer via the Countdown program. Holds have been incorporated at 2 points in the sequence as a precautionary measure to allow operators to double check that the selected control set is as planned. The sequence is initiated by touch panel command to the main Supervisor program which issues the command to all subsystem Supervisors to put their local units in the ready for pulse state.

In response the General Acquisition Program (GAP) reads an operations 'tree' file for all software programmable configuration data, with which shortlists of initialising and data acquisition actions are prepared. This facility allows all CAMAC modules and their control parameters to be defined in a tree structure with an interactive editor. GAP also interfaces to any pulse related routines. In total around 2000 data producing elements are controlled that result in about 8 Megabytes of stored data for each pulse.

At this stage the 2 Flywheel Generators for pulsed electrical field supplies are accelerated toward their operational speed.

A number of specific real-time programs are also run at this stage, such as that to check and reset if necessary the circuit breaker states of the Ohmic Heating circuit.

Any outstanding flags latched from the previous pulse are reset and checks made on software status. A failure to establish necessary conditions on any subsystem results in either an alarm condition requiring manual override or a shutdown, depending on the fault severity.

Arm

Once preparations are completed satisfactorily, all sequences and modules are armed for action. This sequence follows without manual hold from the previous phase. Primarily, the CAMAC modules are loaded with their operational parameters by GAP. The system becomes sensitive at this stage, insofar as control and data loggers will operate their set sequences if they receive a trigger. Some logging is in fact started at this point in order to detect any premature triggering of the most sensitive elements. However, the main power supplies are still inhibited in the local equipment. The automatic countdown is suspended on completion of this phase to allow for final manual checking.

Pulse

The trigger command is given once the final manual check shows all conditions are as planned. From this point the pulse proceeds without any manual intervention until complete. The pulse power supplies are now energised by enabling flywheel generator excitation and switching on the firing pulses of the Toroidal Field static units and the Poloidal Field position control amplifiers. Toroidal cooling pumps are switched to high speed if required. Checks are then made on the readiness to pulse of all components. If they are not, the sequence is aborted.

The Central Timing System is triggered. From this point the entire pulse including control and data acquisition is done at Level 3; in the local CAMAC crates and hardwired logic, totally independent of the computer systems.

The precise sequence of plant controls naturally depends on the type of pulse, but a typical sequence is as follows. Events are determined by CTS pulses, with times taken from the first one (PRE). Data logging may be triggered by a CTS pulse, or by a derived event such as plasma disruption or plant fault.

PRE - Capacitor banks charging started to allow the main ohmic heating switchgear to be operated.
PRE + 25s - CISS is put in Pulse-On state. This is a 'Pulse Enable' window.
PRE + 26s - Toroidal flywheel generator and static amplifiers excited for TF coil current to establish the basic plasma confinement field.
PRE + 30s - Capacitor banks charging is discontinued.
PRE + 36s - Poloidal field power supplies are energised to establish the poloidal pre-magnetisation field. The feedback control system is enabled for plasma generation, current and position control.
PRE + 39.5- Gas introduction enabled, together with plasma density feedback control. If desired pressures are established the following action is enabled.
PRE + 40s - Ohmic heating circuit breakers operate and Poloidal FGC excitation modulated to establish and then maintain the plasma for the 'Fast' and 'Slow' Rise phases of plasma current. Plasma fault protection controls are energised in a CAMAC microprocessor. With the plasma now established, the additional heating sources of Neutral Injection and Radio Frequency are now applied. The pulse continues with all control and protection circuits active until the end of the planned pulse, about 20s later.
PRE + 65 - All power and gas supplies are disabled, if not already so.

The pulse is now defined to be complete and a hold in the automatic sequence is provided to allow operator checks before proceeding. This is essential, as depending on the results of a pulse - not all of which can be foreseen - the post pulse sequence may need to be delayed or cancelled.

Post Pulse

During the Post Pulse phase data is gathered from the CAMAC modules by the GAP program on all subsystems. This is transferred to a Pulse-File on the Storage and Analysis computer and via the high speed link to the Mass Storage and Analysis system at Harwell. A subset is also passed to the Experimental Console computer for immediate automatic analysis of the most important parameters. About 8Mbytes of data are gathered from each pulse. Gathering and concentrating this locally takes around 5 minutes and the transmission to the Mass Storage and Analysis system about another 3 minutes.

In parallel with this data acquisition control routines on the various subsystem computers now carry out any action necessary as a result of the pulse. For example, residual charge and currents in the ohmic heating circuit are removed and the circuitry reset. Cooling pumps are returned to standby speeds and gas valves returned to standby states.

Automatic analysis programs take data from the Pulse-File and display and print results on a variety of devices including a projected colour video screen, VDUs and hardcopy printouts.

This pulsing sequence can be repeated about every 10 minutes, depending on the power of the pulse, the number of subsystems on-line and the amount of data gathered.

CONCLUDING REMARKS

The JET control system is distributed over a wide range of hardware from minicomputers, microprocessors and dedicated hardwired logic. There are at present 19 minicomputers in the on-line network, and there are plans to increase this to around 21 with the extension of additional heating and diagnostics.

However, not all sequences are automatic. In the research and development environment of JET this will always be true, but since the first operation in 1983, repetitive functions of control and parameter selection have been either automated or computer assisted. This evolutionary trend continues, particularly towards automatic design of machine control parameters from demanded plasma profiles.

ACKNOWLEDGMENTS

The fundamental design and implementation of CODAS was led by Dr F Bombi until the end of October 1984, when this role was taken by H van der Beken. They, and all members of the Division, are responsible for the systems described here.

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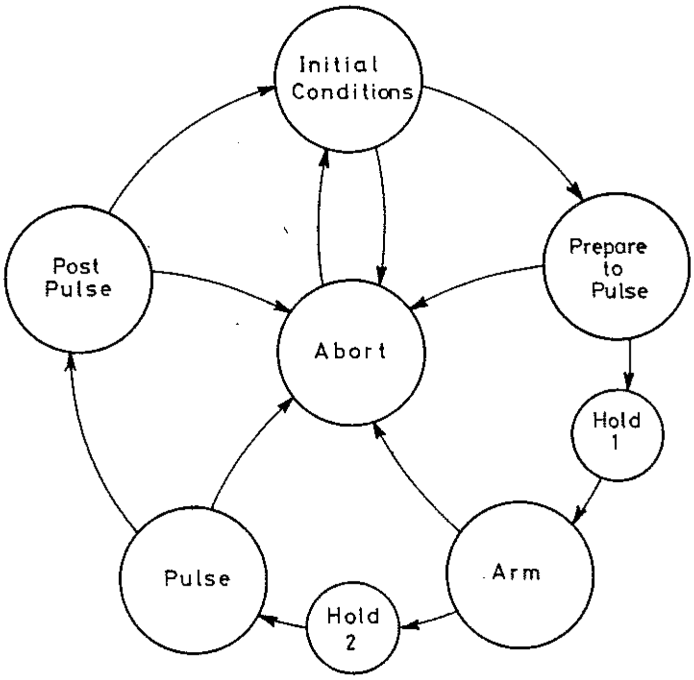

Fig.1. JET Pulse Sequence.

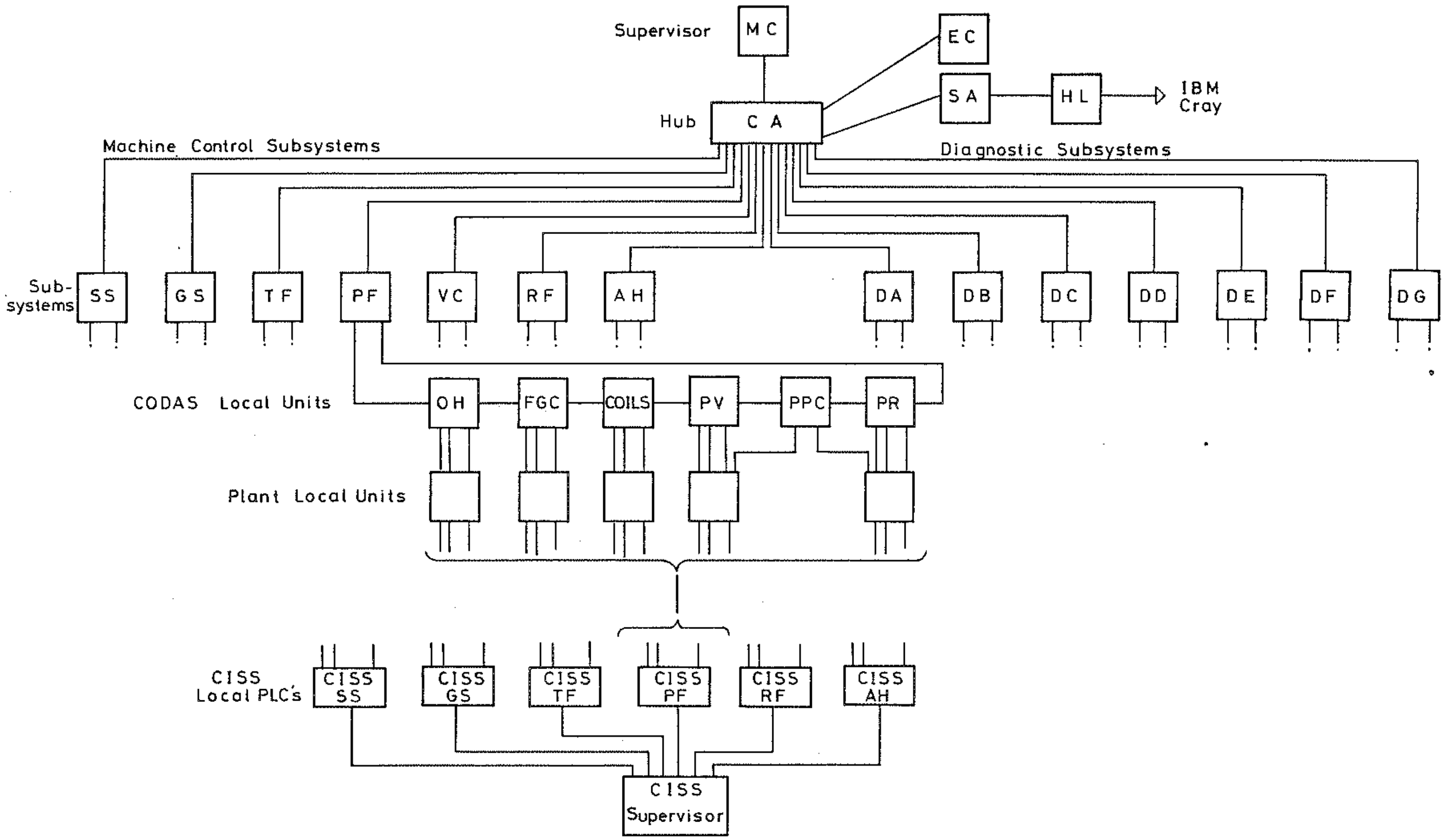

Fig. 2. CODAS Distributed Hierarchical Control