JOINT EUROPEAN TORUS

JET–P(87)19

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Preprint of Paper to be submitted for publication in
IEEE Transactions on Nuclear Science

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COMPUTER CONTROL AND DATA ACQUISITION AT JET

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ABSTRACT

This paper describes the COntrol & Data Acquisition System (CODAS) in use at the Joint European Torus (JET). After a brief description of the Hardware and Software structure and of some of the main developments the role of CODAS in the operation of JET is described.

1. JET Environments

JET is a large Tokamak (major radius R=2.96m, horizontal and vertical minor radii a=1.25m and b=2.10m respectively) designed to study plasmas in conditions and with dimensions approaching those needed in a fusion reactor. A comprehensive status report can be found in [1]. Due to the size of the site (400 x 300m) the number of control and data acquisition channels (∿30,000) a computer controlled system has been designed, implemented and has been in operation since Day 1 (June 1983). The main features of the design are described in [2].

2. Structure of CODAS

The aim of CODAS is to provide a fully integrated control and data acquisition system covering machine control and diagnostics with centralised operation and allowing to follow the construction and expansion programme. To achieve this goal, JET components are grouped into a number of subsystems defined in such a way as to group together the most related functions and minimise communication between different subsystems. This division also took into account the requirements for independent operation and matches the construction and commissioning phases. Beside this "vertical" structure, a "horizontal" structure was specified for both hardware and software. The Level 1 is the supervisory level which co-ordinates the actions of all subsystems and allows central operation. The Level 2 allows operation of a subsystem and Level 3 covers actions on individual components.

The main constraints in the development of CODAS were to take a minimum amount of technical risks in order to guarantee delivery of a working system by Day 1.

2.1 Hardware Structure

Each subsystem is supported by one computer. The interface to the experiment is based on CAMAC instrumentation and signal conditioning uses the EUROCARD standard. When necessary, front end "intelligence" is implemented through CAMAC Auxiliary Crate Controllers based on TMS 99000 microprocessor.

The central operation is performed from two consoles; the Machine Control (MC) and Experiment Control (EC) consoles. Each of them is supported by its own computer.

The communication between subsystems is implemented by a star network using a message switching computer and modified HDLC link working at 1Mbit/s.

The hardware Level 1 comprises the Central Timing System (CTS) which synchronises the operation of all subsystems (resolution 1 micro second) and the Real Time Trigger Network, mostly used for diagnostic synchronisation (Disruption trigger for instance).

All computers are of the same family, NORSK DATA. Depending on the load of the subsystem they are either the single processor NORD-100 (16 bit machine) type or the NORD-500 (16 bit front end, 32 bit back end) type. They are all located in a single computer room allowing easier housekeeping and disponibility of stand-by.

2.2 Software Structure

The lowest layer (Level 3) of software, which appears to the user as embedded in the operating system, allows access to plant signals by names without any reference to "physical" address and any idiosynchrasies of the specific hardware modules and wiring.

The Level 2, specific to each subsystem, provides global commands for each main unit of a subsystem in such a way that they appear nearly identical to the supervisory level.

The highest level, Level 1, is distributed amongst the subsystems and driven from the Machine Control (MC) computer. On each subsystem, a local supervisor has the local knowledge of the various main components. All supervisors are driven in a state machine way.

2.3 Machine Protection

The machine protection has five main layers. In the first instance, as much resilience as possible was included in the design of each JET component. The second layer is made of various limits which can be set locally in components such as power supplies (current and voltage limits) which can be changed according to the mode of operation. The third layer is made by some direct interlocks. Examples of these are the coil protection provided by the Direct Magnet Safety System (DMSS) which interlocks power supplies with coil fault detection equipment and the Protection Plate Viewing System (PPVS) which interlocks Neutral Beam power supplies with temperature sensors of the protection plates.

The fourth layer is provided by the Central Interlock and Safety System (CISS) based on a network of Programmable Logic Controllers (PLCs). Each PLC is programmed to protect a given subsystem and they all implement a simple state machine. A PLC supervisor co-ordinates the state of all subsystem PLCs.

The fifth layer is provided by software implemented either in the subsystem computers for non-time critical protection or in front end microprocessors. Examples of that layer range from the Plasma Fault Protection System which terminates a pulse when unhealthy plasma performances are detected to Coil Cooling analysis which monitors cooling patterns of the Poloidal and Toroidal Field Coils.

3. Main Developments

As with many other facilities, JET had to develop some components of its control system, although all attempts were made to use commercially available solutions whenever possible. The most typical developments are briefly summarised in this section.

3.1 Hardware Developments

3.1.1 CAMAC

In order to cover efficiently long distances and to accommodate conveniently a fair number of crates per loop, the Serial Highway standard has been selected. A Serial Highway Driver has been developed for the NORD computers and is fully integrated in the operating system. It can drive a bit or byte serial loop up to 5MHz with internal or external clock and provide all proper support for LAM handling and DMA operation [3]. The loops themselves are bit serial using fibre optics with main and back-up fibres providing efficient back-up and convenient investigation facilities. A Master U-port (CAMAC jargon for Undefined port) located near the computer provides the electrical to optical conversion and Slave U-ports are installed along the loop where electrical crate connections are required.

3.1.2 Digital Input/Outputs

A very large fraction of the input/output channels to the experiment are of a digital nature. The cabling, isolation and monitoring problems commonly associated with digital input/outputs have been solved at JET with one CAMAC module (CLS2) dealing with up to 512 digital I/Os. This module drives 2 subracks (EUROCARD standard). Each subrack can contain up to 16 cards (16 bit each) of digital input or output of various standard (voltage input, contact input, voltage output, contact output, ...) all isolated up to 1.5kV. Some 2,000 such cards are presently in use. The CAMAC module based on microprocessors provides some local intelligence for input monitoring. Specified inputs can be monitored for any transitions (0 to 1, 1 to 0 or both) and such transitions are signalled to the computer through the Look-At-Me (LAM) facility of the CAMAC loop.

3.1.3 Eurocard Modules

All of the signal conditioning and some additional front end functions have been implemented in the EUROCARD standard (3U(133mm) x 220mm x 4HP(20.32mm)) with 48-way F-connectors. Apart from the digital I/O mentioned previously, the other usage of this standard includes:

- Analog signal isolation amplifiers (1.5kV isolation)
- Active filters
- Analog integrators
- Relay mulitplexer
- Electrical/Optical and Optical/Electrical converters and fan out/fan in modules

3.2 Software Developments

3.2.1 Device Drivers

A full description of the hardware connected to each subsystem computer is fully described in a so called "Hardware Tree". This tree specifies also the point names allocated to each channel. A compact and verified format of this tree is held in memory tables. The Device Drivers are composed of a set of shared re-entrant routines accessible directly from all real time programs or through a server for background tasks. These routines provide a variety of functions allowing the users to access process channels by name and release them of the burden to have to know any physical address or peculiarities of each CAMAC module. A fuller description of this development can be found in [4].

3.2.2 Plant Status Image and Event Management

The Plant Status Image (PSI) concept was implemented at JET in order to decrease the overhead of individual user access to some plant variables. For these variables, an "image" is kept in memory, refreshed at specified intervals and the user accesses this image. This concept has been expanded to derived, or software, variables. Of course, this later class has only one producer and many readers. These variables appear to the users as normal plant variables.

As a natural expansion of the CLS2 monitoring (a feature mentioned in 3.1.2) a complete event management facility has been implemented including all digital PSI variables. Any real time task can link itself to any event and having completed its action go to sleep (RT-wait) avoiding all polling overheads. The task will be triggered (RT'ed) when an event occurs and can obtain the event identification.

3.2.3 Error Reporting

To remedy the common failure of many operating systems to provide a comprehensive, coherent and integrated error reporting system, such a facility has been implemented at JET. The package is based on a layer of subroutines, a message server and patches to the operating system to integrate system and FORTRAN run time error reports. The facility includes error stacking to trace error paths.

In order to facilitate operation of a multi-computer control system all system error devices are connected to a line concentrator which drives up to eight output streams (printer, terminal, ...). The error reporting facility allows to include a destination byte in the error messages in order to direct any message to any combination of the output streams. At present, the following streams are in use:

- Merged stream (all messages)
- Alarm Stream (Plant Alarm logging)
- CODAS Duty Officer Terminal (Summary of operational errors)
- CODAS Duty Officer Printer (Details of operational errors)

The message server operates from a compressed message file "compiled" from source test files very similar to FORTRAN FORMAT statements. This allows errors to be used internally by reference to package number and error number and to be reported in full with parameter substitution where necessary.

3.2.4 Console Support

The man-machine interface is based on consoles driven by CAMAC. Some consoles are permanently based in the main control rooms, others may be connected to any Slave U-port when required for commissioning. The main inter-active devices are Touch-Panels (transparent touch-sensitive surfaces placed in front of a screen) and graphic colour displays with cursor interaction. The console software provides device allocation, device access routines and full support of the touch-panels. On these panels up to 16 "buttons" can be defined by software. The function of these buttons is controlled by software and ranges from displaying a new page of buttons to sending a message to a task on a remote computer.

One of the most commonly used functions is to request the display of a MIMIC display on one of the colour screens. The MIMIC software support developed at JET allows to define in a specialised language a schematic representation of the plant. The variable part is refreshed on changes or at a specified rate. Displayed variables can be local to the subsystem or remote and a full MIMIC can be called from a remote subsystem. Using a Track-ball to control a cursor and action buttons on the Track-ball unit, special interactive points identified on MIMICs can be used for:

- calling another MIMIC (zoom)
- sending a request to a task
- acting on a variable

and other actions.

3.2.5 Alarm Handling

A comprehensive alarm handling has been developed. The main features of the package are:

°logical combination in alarm definition
°time elements in alarm definition (FOR 1 SECOND, for instance)
°priority definition (4 levels used at present)
°logging
°reporting to remote subsystems
°operator acknowledgement
°selective display
°shelving of alarms
°automatic actions
°operator assistance through MIMICs and HELP texts

On all consoles the top part of the colour screen is always reserved for a summary of the alarms known to the subsystem with indication of occurence of new alarms. The main part of the screen can be used, on the operator's request, to obtain a detailed list of alarms. Urgent alarms can use an audible warning and a broadcast on selected colour screens.

3.2.6 Data Acquisition and Archiving

At each pulse of JET some 9MByte of data are collected from all subsystems and archived in a single file called the JET Pulse File (JPF). This collection involves various computers and various real time tasks listed below:

- On each subsystem computer:

  GAP — The General Acquisition Program which, in spite of its name, is also used to set most of the control parameters

  PFM — The Pulse File Manager used to manage the JPFs

  PFXMIT — Pulse File TransMIT program used to send the local JPF to the SA computer

- On the Experiment Control Computer (EC):

  IPFP — The Immediate Pulse File Program which receives a subset of the JPFs and makes it available for immediate analysis and display

- On the Storage and Analysis Computer (SA):

  PFRECV — Pulse File RECeiVe program used to receive the local JPFs from the various subsystem and concatenate them into "the" JPF

  BJPFT — Batch JPF Transmit program used to send the JPFs to the JET main frame (IBM 3090) located 20km through HYPER-channel connection on a 2MBit/s British Telecom link

ANSEND used to send the JPF to the ANalysis computer (AN) through a DMA/DMA link

- On the AN computer

ANRECV used to receive the JPF from SA and to make them available to local analysis programs

The actions and interelation between these programs will be explicited in the next section of this paper. The current performances are:

- Data Capture - 10-16KByte/s - This action takes place on all subsystems in parallel. It involves GAP taking data from the CAMAC front end, sending, if requested, a subset to IPFP (various creaming algorithms), formatting each page of data with header, trailer and checksum and writing the pages to the local disk

- Data Collection - 60kByte/s - This consists of collecting on SA, data from the various subsystems and concatenating them to disk into the JPF. This performance is limited at present by a buffer size limitation on SA which should be removed in the near future. The expected performance should reach about 100kByte/s

- Data transmission from SA - To the IBM through HYPER-channel link - 140kByte/s - A special interface NORD/HYPER-channel is presently under development. Although no spectacular increase of performance is expected, the CPU load created by this transfer should decrease - To AN computer through DMA/DMA link - 200kByte/s - This action includes disk transfer on both machines

4. Operation

During operation weeks JET runs a 2 shift a day system. The beginning and end of each day are devoted to the usual safety and inspection procedures. During this time, the CODAS duty officer inspects all error logs of the subsystem required by the program and checks on MC that all relevant subsystems are included in the count-down using MIMICs to verify and

Touch-Panels to modify the selection. The responsible officers of the main system ensure that the mode of operation is as required by the program (Poloidal Field, Toroidal Field, Neutral Beam). Then they can use dedicated Level 2 software to set and check the configuration depending on the mode of operation. When this is completed successfully the CISS can be reset to its NORMAL state and the machine is ready for operation. The first pulse of the day is a "dry-run" to ensure, without power, that all systems appear to run properly through the various phases of the pulse. The second pulse of the day has practically fixed parameters to check the density limit before starting real operation. For these two pulses a central parameter setting facility is used and all parameters set through a touch-panel "button". For all other pulses the various phases, explicited below, are:

- Parameter Selection
- Prepare to Pulse
- Pulse
- Post Pulse

4.1 Parameter Selection

For each session a pulse schedule has been prepared by the Session Leader and the Engineer-in-Charge. For each pulse the operators select through special tools the various machine control parameters and protection system windows. Some of them are listed below:

- Power supply waveforms - Uses the Waveform Selection program through colour screen menus and cursor interaction

- GAS introduction - Uses dedicated program with representation on colour screen

- Plasma Fault Protection System limits - Uses Touch-Panel and colour display

- Neutral Beam - Uses a sequence of Touch-Panel "prompts" driven by a program which checks validity of some values

Most of the selected parameters are not set directly but the values are written in a file with a Tree structure which is used in the prepare to pulse phase.

4.2 Prepare to Pulse

This phase, as the two following ones, is driven by the Count-Down program. Each of them is triggered by a Touch-Panel button. The Count-Down program is data driven and implements a state machine with automatic and operator triggered transitions. It is running on the Machine Control computer communicating with the selected subsystems and its progress is monitored through a MIMIC diagram. The Count-Down program instructs local Supervisor Tasks, on each subsystem, to progress through their specific sequences (data driven) within the framework of a global state machine. On each subsystem the supervisors control two main classes of actions, the Level 2 software and GAP.

The Level 2 software is a collection of tasks, one for each main unit of a subsystem. Each task implements the proper sequencing to drive each unit through its required sequence.

GAP is a data driven program. The data are stored in a Tree-like structure called the GAP-tree. During the Prepare to Pulse phase GAP visits the Tree, checks for consistency and prepares memory short lists. The lists specify actions to be done before the pulse (parameter setting, waveform loading, arming CAMAC modules, etc) and actions to be taken after the pulse (data to collect from CAMAC front end, data to send to IPFP on EC, etc). During this phase, GAP requests PFM to allocate a new JPF file.

When all hardware units have been found ready for operation and all GAP trees have been checked, the parameter setting proceeds and after checks on proper loading the Ready to Pulse state is reached, the Count-Down reports it and awaits operator instructions.

4.3 Pulse

When the Ready to Pulse state is reached the operation team checks that the parameters are according to schedule, including last minute changes, and when satisfied, triggers the Pulse phase. In this phase the firing pulses on the power supplies are enabled, last status checks are made and the Central Timing System triggered. From this point the computers are not involved in Real Time activities except for the display of some main parameters like Plasma Current, Toroidal Field and Density.

All real time actions are done either by direct feedback loops or by front end microprocessors. Amongst the latter, the main functions are:

- Plasma Fault Protection System - Monitors Plasma performances and "softly" terminate the pulse if required and interlock Neutral Beam

- Plasma Density Feedback - Controls the dosing valve to maintain required plasma density

- Plasma Current Feedback - Controls the Poloidal Field generator to maintain the required plasma current

- Plasma Density Validation - Monitors various density diagnostics and derives a validated density and a degree of confidence

- Waveform Generators - all analog waveforms are generated by front end microprocessors

After the CTS trigger, the Count-Down program awaits operator instruction.

4.4 Post Pulse

After physical completion of the pulse and if no untoward events have occurred, the Post Pulse phase is triggered by the operator. During this phase the Count-Down controls, through the local supervisors, the following actions:

- The various Level 2 tasks put all local units back to their idle state

- GAP performs the required data acquisition and sends to IPFP a subset of the JPF

- On EC, the main parameters of the pulse are analysed and a summary of the results are displayed on colour screens

- When local JPF is complete, PFM instructs PFXMIT to send the data to SA

- When the JPF on SA is complete PFM instructs BJPFT to send the JPF to the JET Main Frame for further analysis and ANSEND to send the JPF to AN for local processing

When all Level 2 have completed successfully and when GAP has secured on local disk the local JPF, a new pulse may re-start.

5. Developments

The main ongoing developments are in the following fields:

- Expansion of the system to cover JET extension like Tritium Plant and Low Hybrid

- Improvement of performances specially in the field of data collection and transfer to cope with the expected growth of the JPF size to 15MByte per pulse

- Development of a comprehensive set of facilities to allow: Session Leaders to prepare and check pulse schedules; Operation Team to select parameters more efficiently

6. Conclusions

The Hardware and Software structures of CODAS have been found suitable for the commissioning, operation and development of JET.

The subsystem concept has proven its flexibility to adapt to the various modes of operation.

The various layers of software, and particularly the Level 2 concept allowing to make all local units look alike, have been successful.

The concept of data driven software has shown to be flexible and to allow a fair protection between application codes and sequence of actions.

The usage of front end microprocessors has grown much more vigorously than anticipated at the design phase and indicates a clear trend for future control systems.

7. Acknowledgements

The work reported in this paper results from the effort of many dedicated members of the JET staff helped by the support of various contractors. Some of them are working now on different projects. Special acknowledgements are

due to the following people: Dr F Bombi who led the implementation until October 1984; K Fullard, EM Jones and CA Steed who are leading the Electronics and Instrumentation Group, the Data Acquisition Group and the Control Group respectively; V Schmidt in the field of CAMAC loop and CTS design and installation; JP Nijman and JE van Montfoort in the field of CISS; SE Dorling in the field of CAMAC instrumentation; RF Herzog, JH Hobson and CH Whittington in the field of operating system installation, development and operation; ML Browne, T Budd, HE Clarke, JF Krom, GD Rhoden, BA Wallander in the field of subsystem development; JJ Saffert and MR Wheatley in the field of data acquisition and archiving; RKF Emery, JDW Harling, DS Nassi in the field of console development; PA McCullen (TRASYS) and K Reed (System Designers) who are leading two teams of programmers.

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