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C O D A S

THE JET CONTROL AND DATA ACQUISITION SYSTEM

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Summary

JET - The Joint European Torus - will be a major step in the European Community's fusion program. The principal objective of the experiment is to obtain and study a plasma in conditions and dimensions approaching those needed in a thermonuclear reactor. The size and complexity of the experiment demands an integrated computerized control and data acquisition system. CODAS comprises machine monitoring and control, acquisition of plasma and machine data, data analysis and storage. It is divided into several almost self contained subsystems, each of which is controlled and serviced by a minicomputer. The various local units of each subsystem are interfaced through CAMAC.

The communication between the centralized control and the subsystems is obtained through 3 communication paths, the computer communication, the timing and the interlock system.

The experiment as a whole is operated from two consoles, the machine console and the experiment console. One computer with large storage capacity is foreseen for the filing of all data, for automatic data processing between two pulses and for further analysis programs.

1. The JET Experiment

JET is a proposed major European thermonuclear fusion experiment, intended to be the mainstay of the fusion program of the European Communities for the next decade. The experiment has been designed by a team of European scientists and engineers at UKAEA Culham Laboratory. Similar devices are under design or in the early phase of construction in USA (TFTR), USSR (T-20) and Japan (JT-60).

A detailed description of the objective of the JET experiment and of the design of the JET machine is given in [1] and [2]. Here only a brief outline is presented.

The essential objective of JET is to obtain and study a plasma in conditions and dimensions approaching those needed in a thermonuclear reactor, that is, densities approaching 10^{14} particles cm^{-3}, temperatures exceeding 5keV and plasma minor radii 1.25 x 2.1m (oval cross section). These studies will be aimed at defining the parameters, the size and the operating conditions of a Tokamak reactor.

JET is based on the promising Tokamak plasma confinement scheme which was first developed in the USSR. Fig.1 is an artistic view of the JET apparatus. The main components and their functions are:

- A toroidal D-shaped vacuum chamber (1) is filled with hydrogen, deuterium or, in a later phase, with a deuterium/tritium mixture at a low pressure, typically 10^{-4} Torr.
- The gas is ionized and a toroidal gas current is induced by changing the current in the primary coils (2) of an iron core transformer. The resulting plasma is heated by the current of typically 3MA up to temperatures of ~1keV, the "poloidal field" associated with the plasma current provides the plasma confinement.
- Additional poloidal fields are created by currents in external poloidal field coils (3) in order to keep the plasma in equilibrium and to shape its cross-section in an appropriate fashion.
- A strong toroidal magnetic field, typically 3T, is required in order to suppress dangerous plasma instabilities. This field is established prior to the discharge by currents in 32 toroidal coils (4) which surround the vessel.
- The Ohmic heating by the plasma current is insufficient to raise the plasma temperature up to ≥5keV. Additional heating will be provided by powerful neutral particle injection (initially ~10MW) through radial ports (5).

The Tokamak operation is basically pulsed. In JET the pulse duration is up to ~20s and ~10minutes are required to restore initial conditions (vacuum, temperatures) of the apparatus before the next pulse.

The various components of the JET apparatus have to be operated in a safe, controlled and co-ordinated way and a large number of data from plasma diagnostic equipment and of engineering data has to be acquired during each pulse and stored(Table I).

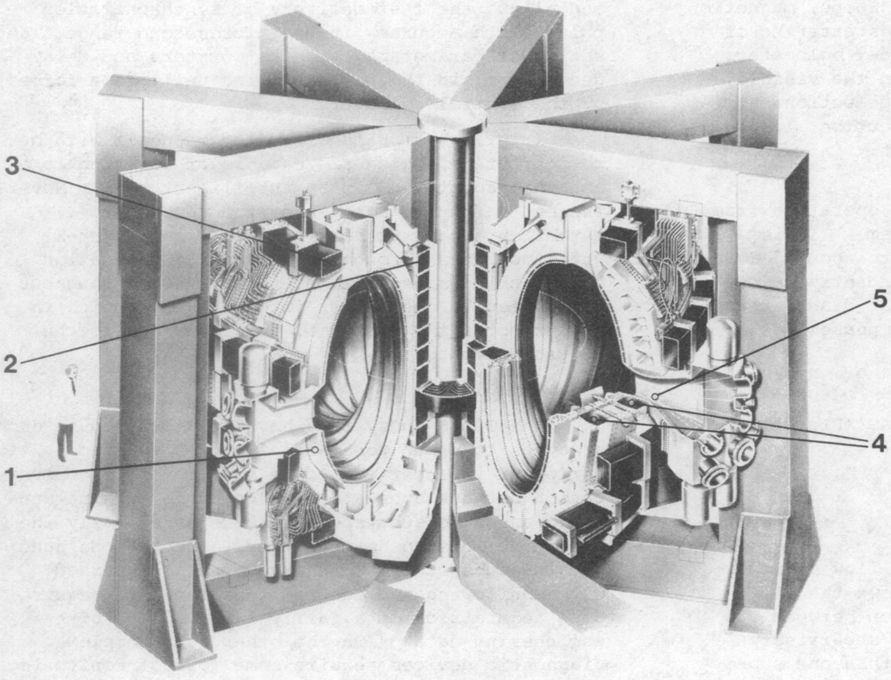

Fig. 1 THE JET DEVICE

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Moreover, these data will be analysed and basic results will be presented after each pulse. For this purpose an integrated computerized control and data acquisition system (CODAS) has been conceived and is presently under design.

2. Outline of the Control and Data Acquisition System.

In order to simplify the design, the construction and the commissioning of the CODAS, the JET machine equipment and the diagnostic devices are grouped into a number of almost independent machine and diagnostic subsystem.

Machine Subsystems:

- Toroidal Field (T.F.) subsystem. (T.F. coils, T.F. power supply and T.F. cooling system).
- Poloidal Field (P.F.) subsystem. (P.F. coils, P.F. power supply, P.F. switching network, power amplifiers for plasma position and shape control,and P.F. cooling system).
- Vacuum subsystem. (pumping systems for torus vacuum, injectors vacuum, module joint vacuum and shell vacuum, bake-out heat generation plant, limiters, tritium handling and gas filling system).
- Mechanical Structure.
- Additional Heating. (neutral injectors and additional heating power supplies, radio frequency heating).
- General Services. (electrical supply, water cooling and miscellaneous).
- Safety of Personnel. (access control and radiation monitoring).
- Remote Handling.

Diagnostic Subsystems:

For the measurement of plasma parameters, such as electron density, electron and ion temperature, energy losses, fluctuations, impurities, plasma position and shape, poloidal magnetic field, the following diagnostic methods will essentially be applied:

electrical measurements (Rowgowski loops, magnetic flux loops, "dia-magnetic loops"); scattering of laser light; dye laser fluorescence; bolometers and thermocouples; spectroscopy in the visible, u.v. and vacuum u.v.; soft X-ray detection; hard X-ray detection; neutron detection; charge exchange neutral particle detection; infrared interferometer; microwave systems.

Most of the diagnostics will be in operation from the beginning of the experimental program. It is intended to allocate these diagnostics to about 5 CODAS subsystems which can be operated independently of the central control if required. Additional diagnostics will be applied during the experimental phase and connected to CODAS in the same way.

2.1. Hierarchical structure

The proposed structure of CODAS (Fig.2) is organized in 3 hierarchical levels:

1st level	supervisory level
2nd level	subsystem level
3rd level	local unit level

In the proposed structure the flow of information and of control signals follows the hierarchy of the system: communication between two subsystems is obtained through the supervisory level and similarly local units within one subsystem communicate through their subsystem level.

2.2. Supervisory level

The supervisory level provides the overall control of the experiment, both from the machine and from the diagnostic point of view. The interaction between man and machine is performed at this level by means of two main consoles; the machine console, used to control the operation of the machine, and the experiment console, used to control the plasma diagnostics and to display the experimental results. All commands required to set up the machine parameters for the next pulse (timing, reference values, reference functions, etc.,) will be issued via the consoles and dispatched to the machine and diagnostic subsystems. Conversely status information and experimental results are to be properly presented on the consoles' displays.

The main functions to be performed at the supervisory level involve the use of 3 computers:

- control computer - to drive the machine console, to perform validation tests on the operator commands and to co-ordinate the operation of the machine subsystems.
- display computer - to drive the experiment console, to provide a number of other display facilities in the control area, and to co-ordinate the operation of the diagnostic subsystems.
- storage and analysis computer - to provide a large centralized filing facility for the whole system and to execute basic computational codes on the experimental data.

Exchange of information between subsystems is also part of the supervisory level. Since the whole system is computer based most of the communications involve exchange of messages between computers which contain information concerning control actions, status reports, and measured data.

An independent communication path will be used to exchange timing signals. This path links a master timing unit to all subsystem timing units and allows the fast delivery of synchronization pulses with accuracy in the microsecond range. The set up of parameters, such as counters and delay generators, in the master timing unit is performed by the control computer.

Interlock signals will also be dealt with by the computers, which are capable of reacting to abnormal conditions in an intelligent way. Nevertheless safety reasons make it necessary to establish a back up hardwired interlock system which operates through a separate communication path linking subsystem interlock units throughout the system to one master interlock unit which in turn reports the status of the interlock to the control computer.

2.3. Subsystem level

The CODAS subsystems have been defined in such a way as to group together the most related equipment in order to reduce the amount of communication between subsystems. Both the machine and the diagnostic subsystems require essentially the same functions to be performed. On the one hand machine subsystems, which are mainly concerned with monitoring and control functions, do require also acquisition of a fairly large amount of engineering data. On the other hand complex diagnostic devices require some form of monitoring and control actions besides the acquisition of experimental data (Table I). Consequently a

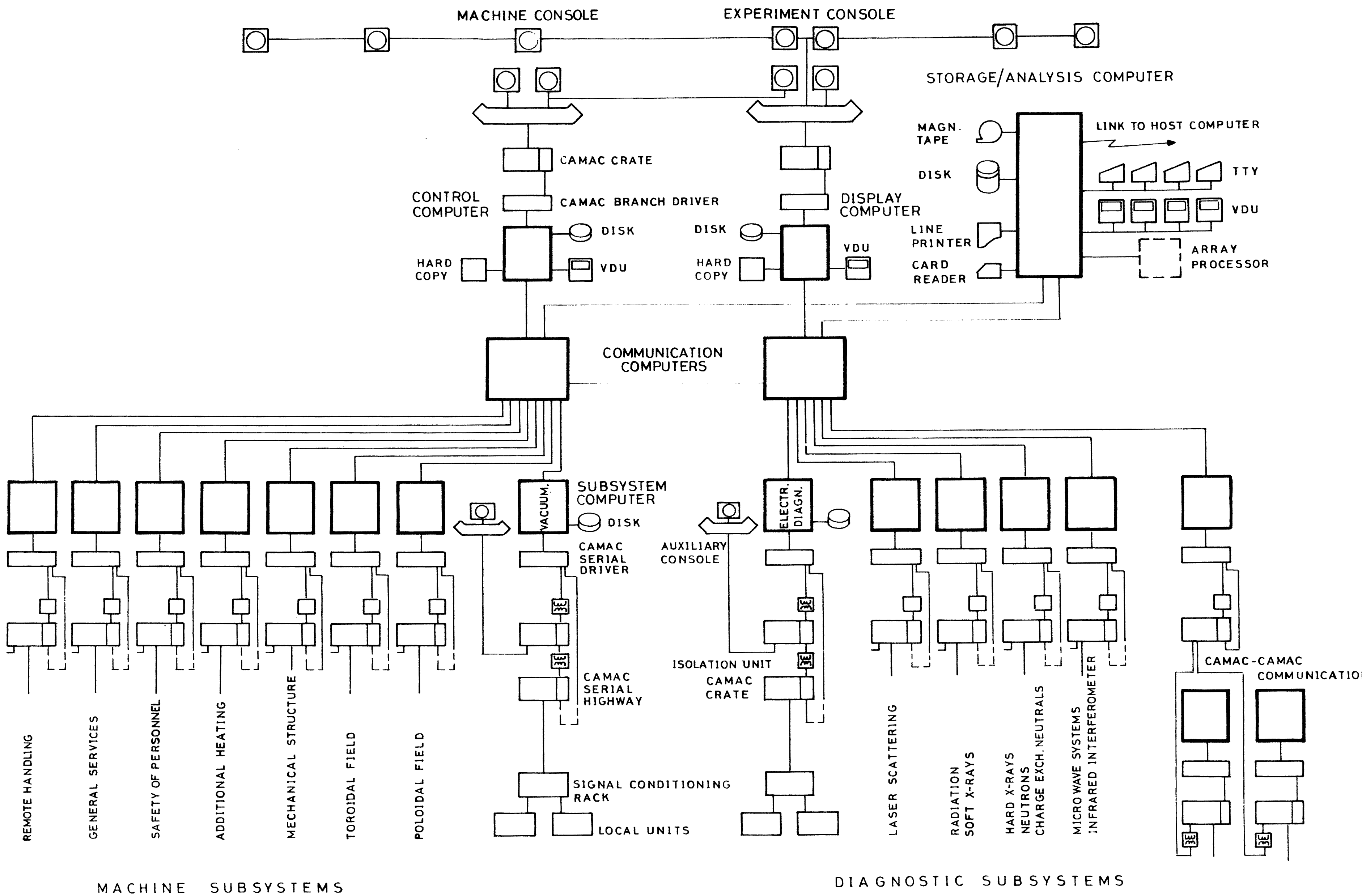

Fig.2 CODAS-THE JET CONTROL AND DATA ACQUISITION SYSTEM

unified structure is adopted for all subsystems, in which a computer is used to provide the functions required. (Fig.2)

The local units will be interfaced through CAMAC modules and a CAMAC Serial Highway configuration will be used.

Timing signals required for the subsystem operation will be generated by a subsystem timing unit which is set up by the subsystem computer and triggered by signals received from the supervisory level.

Interlock functions at the subsystem level will be ensured by a subsystem interlock unit, the status of which will be reported to the subsystem computer.

2.4. Local unit level

The local unit level includes all diagnostics and all parts of the machine which are interfaced to CODAS; a great variety of devices performing different functions belong to this level, however a standard approach is suggested for the interconnections between the second level and the local units. The use of signal conditioning racks, housing cable terminations, signal conditioners, special electronic devices, etc., is envisaged so that only a few different types of CAMAC modules may be used throughout the system.

3. Computers and Software

The use of a number of computers is required to cope with the amount and variety of functions to be performed by CODAS. The proposed multicomputer system (Fig.2) has been defined with the aim of specializing the functions that are assigned to each computer so that its hardware and software configurations could be chosen to best match specific tasks.

Computers of the same type and with similar configurations will be used for all machine and diagnostic subsystems, since they have to provide the same type of real time I/O oriented services. The control and display computers must be capable of handling a large number of interactive and graphic devices and both will have similar configurations. The requirements of the computer communication system have been investigated and a solution using two dedicated processors has been proposed. The two processors will separate the traffic related to the machine subsystems from the flow of data which originates from the diagnostic subsystems. The functions of the storage and analysis computer require a number crunching type of machine with large mass storage facilities and capable of supporting a number of terminals.

It would be advantageous if these requirements could be met by different models and different configurations of the same family of fully compatible computers. The software development effort would then be kept to a minimum and maintenance problems, both for the hardware and the software, would also be reduced.

A preliminary enquiry has been sent out to a number of computer manufacturers asking for proposals and budgetary prices for a system of computers to be used in CODAS. The replies from the manufacturers are being evaluated at present in order to prepare a formal call for tender which will lead to the final choice of the computers.

The basic software requirement for the CODAS computers is the availability of a real-time operating system which should have the capability of being tailored to meet a wide range of demands. As far as the choice of languages for the development of CODAS is concerned, the use of three different types of language is envisaged. ANSI standard FORTRAN will be used for the development of analysis programs so that portability in the fusion community will be ensured. A high level "system implementation language" will be adopted for the development of the basic real-time software. The third type of language will be of "interpretative type" and will be used when direct human interaction is involved. Interpretative languages have proved to be quite effective for the development of process oriented software and as a means to perform test and maintenance procedures. This high level language will provide suitable I/O features to drive the CAMAC hardware and will include real-time facilities to synchronize the programs with the experiment timing. In order to retain the advantages of easy debugging and, at the same time, to satisfy the need for fast executing codes, the availability of a compiler for the same language is desirable.

An important part of the system software, common to all the computers, is the one concerning the computer communications. The communication software will be fully transparent to the user. It will have a layer structure in order to separate the hardware dependent code from the system and user software. Facilities for inter-processor task to task information exchange and for remote file access will be available.

4. Man-machine Interface

The man-machine interface has to provide facilities for control of the machine and diagnostics and for analysis of experimental data.

During normal operation one experimental team and one operating team will be involved in carrying out the experiments. The experimental team will be responsible for selecting the plasma parameters and configurations (modes of operation), and will require the display of global information from the experiment and of results of computations performed on the acquired data. The operating team on the other hand will be responsible for implementing the selected modes and for safe operation of the machine.

Two main consoles will be provided for the operation of JET: the experiment console and the machine console.

The control devices in the consoles(VDU's, keyboards, touch panels etc.) will be connected to a computer, so that the method of control may be modified by software with no need of changes in the hardware. It is intended to make extensive use of suitable interactive devices such as programmable touch panels which provide a simple and flexible means of selecting desired functions.

The communication between the experimental team and the operating team will be established through a standardized procedure by means of dedicated sections in the consoles. Thus, the experiment operator will be able to communicate with the machine operator in order to pass the information concerning the mode of operation to be established, and to follow its actual implementation.

A number of auxiliary consoles, directly connected to the subsystem computers by means of the CAMAC Serial Highway will allow each subsystem to be independently operated. These consoles are movable so that they may be placed near the controlled equipment during the early commissioning stages; they can then be moved into the control area to perform commissioning of more than one subsystem and for normal maintenance operations when collaboration between operators is required. During normal operation the machine subsystem consoles will be in the control area and will display information from the subsystems. Diagnostic subsystem consoles will be used by experimentalists interested in specific diagnostics. The auxiliary consoles can also act as a back up means for running the experiment in case of a failure of the central control.

5. CAMAC Interface

The CAMAC standard will be used to interface the local units and conditioning racks to the subsystem computers. Furthermore, all console devices will be connected to computers by means of CAMAC modules (Fig.2.).

The CAMAC Serial Highway will link different CAMAC crates of a subsystem which are geographically distributed and will allow isolation and by-passing of each crate to be easily achieved.

The required monitoring, control, data acquisition interlock and timing functions can be provided by specifying few CAMAC modules.

- For data acquisition the use of autonomous data collecting devices is proposed which do not require any processor intervention. Three different types of analogue to digital convertor modules with or without multiplexer or memory module will perform most of the data acquisition functions.
- Monitoring and control functions, such as generation of reference values, limit comparison etc., will be performed using digital input/output modules. Digital to analogue conversion will take place in the conditioning racks.
- Timing functions within each subsystem will be provided by programmable pulse generator, time of day generator, and interval timer modules.
- The status of the subsystem interlock will be reported to the subsystem computer through CAMAC digital input modules.

REFERENCES:

[1] "The JET Project - Design Proposal" (EUR-JET-R5) EUR 5516e. Commission of the European Communities, Luxembourg (1976).

[2] "The JET Project - Scientific and Technical Developments 1976" (EUR-JET-R8) EUR 5791e. Commission of the European Communities, Luxembourg (1977).

Table I: Subsystem Requirements

Machine Subsystems:	Monitoring Channels	Control Channels	Data Acquisition Channels
Toroidal Field	400	25	145
Poloidal Field	230	160	60
Vacuum	2000	1850	520
Mechanical Structure	400	--	400
Additional Heating	1800	1000	700
General Services	200	150	50
Safety	300	150	50
Remote Handling	500	700	250
Engineering data to be stored:			
$\lesssim 10^5$ data values	$\simeq$250 k bytes/pulse		
Diagnostic Subsystems:			
Diagnostics	150	150	400
Diagnostic data to be stored:			
$\lesssim 10^6$ data values	$\simeq$2.5 M bytes/pulse		

Table II: CODAS performance parameters

Total storage capacity: ~1000 M bytes (disk)

Data to be stored every pulse: $\leqslant$ 2.5 M bytes

Time to collect, transfer and file data of 1 pulse: < 90 sec

Communication lines transmission speed: ~ 100 k bytes/sec

Total service time for control messages :< 5 ms

(JET experiment pulse duration: 20 sec; time between pulses: 10 min.)