

Design and Implementation of a Real-time Power Control System at JET

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ABSTRACT

Experiments on JET require reliable control of basic plasma variables such as density, temperature and reaction rate. The real-time power control system provides a significant advance in the control capabilities by deriving suitable plasma heating rates and gas introduction rates in real time based on diagnostic information from the plasma. The most innovative feature is to provide control room staff with a safe and easy method of defining control scenarios known as networks on-line. These networks can be tested immediately with data from previous pulses and then loaded for the next pulse. This paper presents details of the engineering design of the system.

1 INTRODUCTION

Recent control experiments at the Joint European Torus (JET) require reliable control of fundamental physics variables such as plasma density, temperature and reaction rate. The basic design objectives for the control system are:

- To create a flexible and easy to use environment in which different scenarios of automatic control of plasma variables can be designed and implemented.
- To linearise and optimise the dynamic response from plasma heating systems.
- To allow rapid off-line testing.
- To allow changes to be made to control scenarios between pulses.
- To provide automatic control of all JET plasma heating systems and gas introduction system.

The method chosen was to develop a dedicated control language. The user can define up to 4 control networks, each with up to 200 algorithms. These algorithms are effectively virtual control circuit components. The networks can be tested and loaded in a few minutes by means of a special user interface, which is provided as a part of the global JET pulse control software.

2 OVERVIEW

The implementation of the control system is divided into a global layer and a subsystem layer as illustrated in Figure 1.

The subsystem layer has independent controllers, called “Local managers” dedicated to each plant element. These managers translate from reference signals in Engineering units (eg. MW) to plant control voltages. The reference can be a pre-defined waveform for independent operation but for real-time control purposes it is generally received from the global control layer.

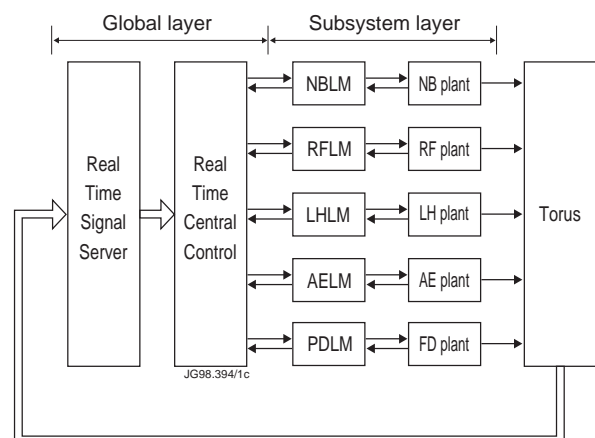


Figure 1 Overview of Control System.

The global layer consists of two systems: The real-time signal server (RTSS) and the central controller (RTCC). RTSS acquires around 200 diagnostic signals and scales them to engineering units. Signals are received in analogue form and converted in ADC modules, or as datagram packets over a 10Mbits/s Ethernet connection.

RTCC is the heart of the system. It processes the diagnostic information according to the software networks defined by the user and derives output signals to drive the various JET heating and density control systems. These outputs are sent over the Ethernet to the appropriate local manager.

3 HARDWARE IMPLEMENTATION

The local manager, signal server and central controller computer systems are all based on the VME bus and use two MC68040 processor cards running the VxWorks operating system. In each case one processor is connected to a 10Mbit/s Ethernet segment and runs communications code. The other processor is free of network related interrupts and runs the real-time code. This enables the system to process data at up to 1kHz with an acceptably low jitter. All communications between processors is via memory read and writes over the VME bus.

4 SOFTWARE

4.1 The Control language

A special control language has been developed for the JET real-time control system, see reference [1]. Users define up to 4 control networks which are loaded into a front-end controller and executed during a JET pulse. These networks consist of up to 200 virtual control circuits, or algorithms. These “circuits” read diagnostic signals from the signal server, manipulate them and then use the derived values to control the plant. Sequences can be triggered according to the result of various logic circuits. Plant can be controlled by predefined waveforms or by the use of feedback loops, and outputs can be constrained to lie within pre-defined limits as required.

4.2 The Editor

A simple editor is provided to write and manipulate the networks. An example of an editing screen is shown in figure 2. At the top of the display window the editor has a number of buttons for enabling heating systems, for loading networks into plant, and for testing networks. Underneath is the main editing window. Networks can be retrieved from standard directories or from previous pulses and then modified or reused. The edit is fully menu driven allowing the user to select algorithms from a list. Recent enhancements provide facilities for moving around blocks of lines and automatically updating the line number references throughout the network. This greatly assists in the maintenance of logically presented code.

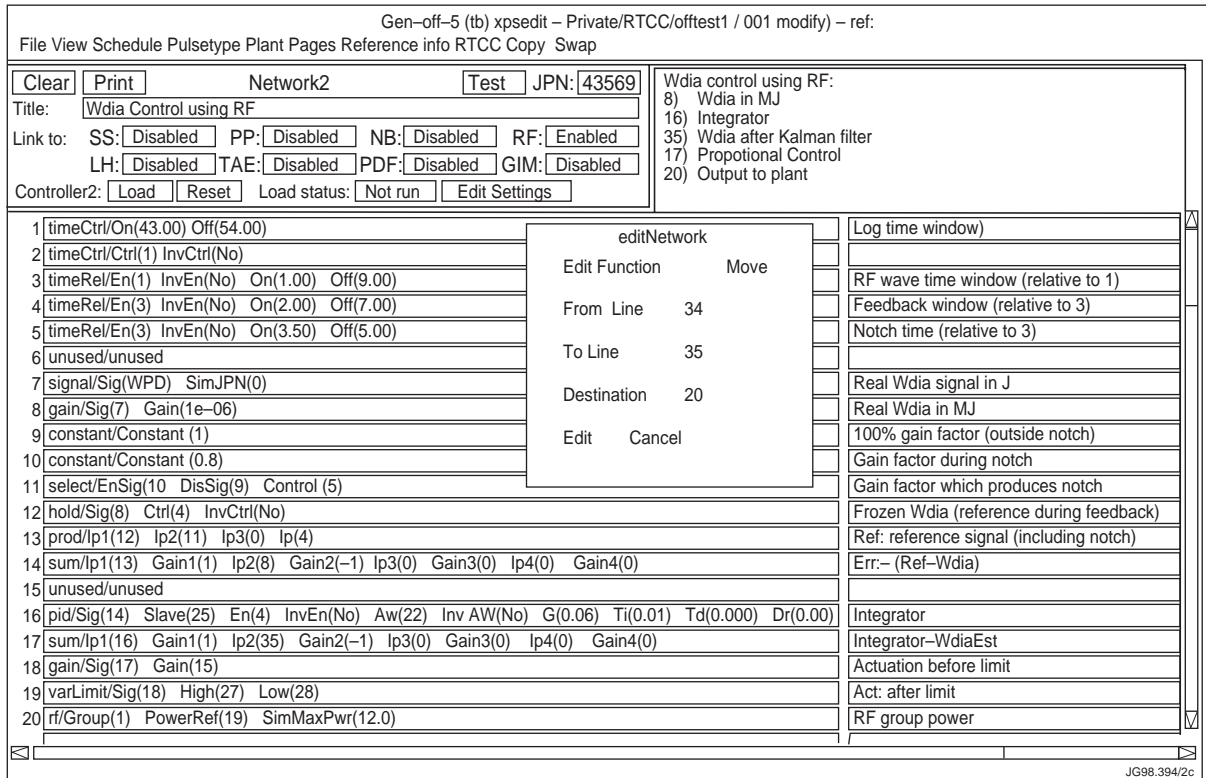


Figure 2. Network Development Using Editor.

4.3 Network Display and Test facilities

It is quite hard to visualise the operation of complex control networks from a simple line by line listing. For this reason a graphical display program has been written. This automatically sorts the algorithms into execution order and presents them on the page in a logical manner. An example of such a display is shown in figure 3.

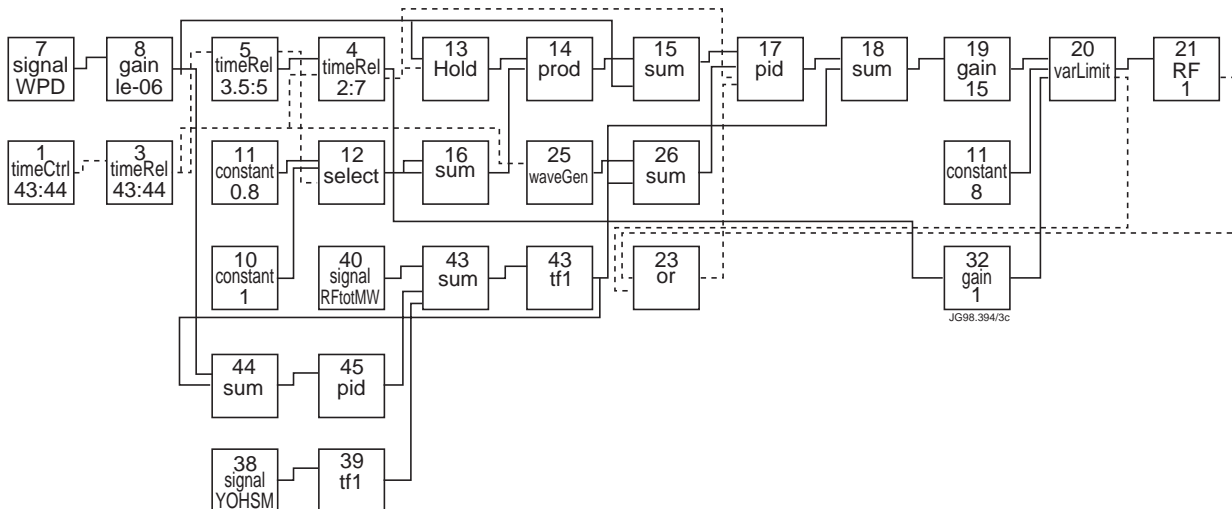


Figure 3. Automatically Generated Flow Diagram for W_{dia} Control Network Using RF.

A crucial requirement of the system is the ability to test networks off line. This has been implemented by providing a copy of the central controller on the UNIX host. Testing the network simply requires the push of a button. During a test previously logged signal data can be replayed through the signal algorithm. Alternatively a commissioning waveform may be used to test specific features of the users network.

4.4 Method of Operation

Once a system is tested it can be loaded at the touch of a button. Plant outputs are then enabled as required and the network is ready for a JET pulse. Results may be displayed immediately after a pulse using a graphical interface which allows individual display of the output of every algorithm in the network. An example is shown in figure 4. If the results require further modifications to be made these can be done immediately and the the new network tested using previous data and reloaded within a couple of minutes, easily in time for the next pulse.

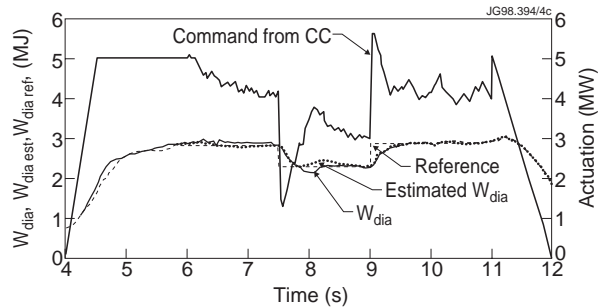


Figure 4 Signals of Interest from the W_{dia} Control Experiment

5 EXAMPLE OF USAGE

A simple example will illustrate the capabilities of the system. Control of the plasma stored energy, W_{dia} is readily achievable using RF heating. The plant dynamics are predominantly first order, the time constant being the energy confinement time which is typically 400 ms for a JET plasma. A modest RTCC network of about 30 algorithms is all that is required. A first order Kalman filter provides a low noise estimate of the stored energy. This signal is used for proportional feedback acting predominantly in the higher end of the controller frequency range. The network used is shown in figure 3 and figure 4 shows the results of using the network. The controller achieves a settling time of the order of 0.5s. The noise level is reduced by an order of magnitude by the Kalman filter.

Other examples of usage are given in reference [2]. Recently the system was used extensively during the JET tritium experiments in order to control Neutral Beam and RF heating power to meet neutron production profiles. It also played a vital role in shutting off heating pulses that deviated from their expected performance, thus keeping the tritium experiments within the allocated neutron budget, and minimising activation of the JET vacuum vessel.

6 SUMMARY

The basic real-time control system has been in operation for two years, and has been extended to provide a robust and reliable method of developing control algorithms for a wide variety of experiments. The ability to develop and test networks safely within an experimental session has proved especially valuable. The system played a vital role during the JET tritium experiments by controlling Neutral Beam and RF heating power to meet target neutron production profiles, while minimising unnecessary activation of the vacuum vessel.

REFERENCES

- [1] Zornig et al., Experimental Results using the JET Real-Time Control Network 19th SOFT 1996.
- [2] King et al, An Experimental Automatic Control Facility at JET. Accepted for publication in Fusion Technology 1998.