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Digital real-time plasma control system for Alcator C-Mod

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Abstract

A new digital plasma control system (DPCS) has been implemented for Alcator C-Mod. The new system was put into service at the start of the 2005 run campaign and has been effectively controlling the machine since then. This system not only provides a drop-in replacement for the original C-Mod control system, which was becoming increasingly difficult to maintain, it also provides a flexible platform to explore new non-linear and adaptive control schemes. It consists of two 64 input, 16 output CompactPCI digitizers attached to a rack mounted Linux server, which performs both the I/O and the computation.

During initial operation, the system is set up to directly emulate the original C-Mod control system: this comprises a matrix of linearized observers, which estimate the 16 physical quantities under control, 16 PID channels for the conditioning of the errors between the physical quantities and their pre-programmed target waveforms and a matrix of controllers, for feeding back to the power supplies and other actuators. The matrices, the target and feed-forward waveforms and the other control parameters are time dependant and switch according to the particular phase of the plasma discharge. The compatibility with the previous control system allows the existing user interface software and data structures to be used with the new hardware. The controlling program is written in IDL, from Research Systems Incorporated (RSI), and runs under standard Linux. Interrupts are disabled during the plasma pulses to achieve real-time operation.

Emulation of the original control algorithms is accomplished using 50 μs per iteration, with the time evenly split between I/O and computation, so rates of about 20 kHz are achievable. Reliable vertical control can be maintained with cycle rates as low as 5 kHz so there is considerable headroom for extra computation.

The next steps are to explore the operation of the system on multiple time-scales, the use of additional computers in the real-time loop and the implementation of user provided signal processing and control schemes. These would include real-time analysis of power supply demands, real-time MHD modelling, and adaptive response to non-standard (unplanned) discharge conditions.

Keywords: Plasma control; Data acquisition; Alcator; MDSplus

1. Hybrid control system

Alcator C-Mod [1] is a high field compact tokamak that has been in operation at the Massachusetts Institute of Technology since 1993. Its original hybrid

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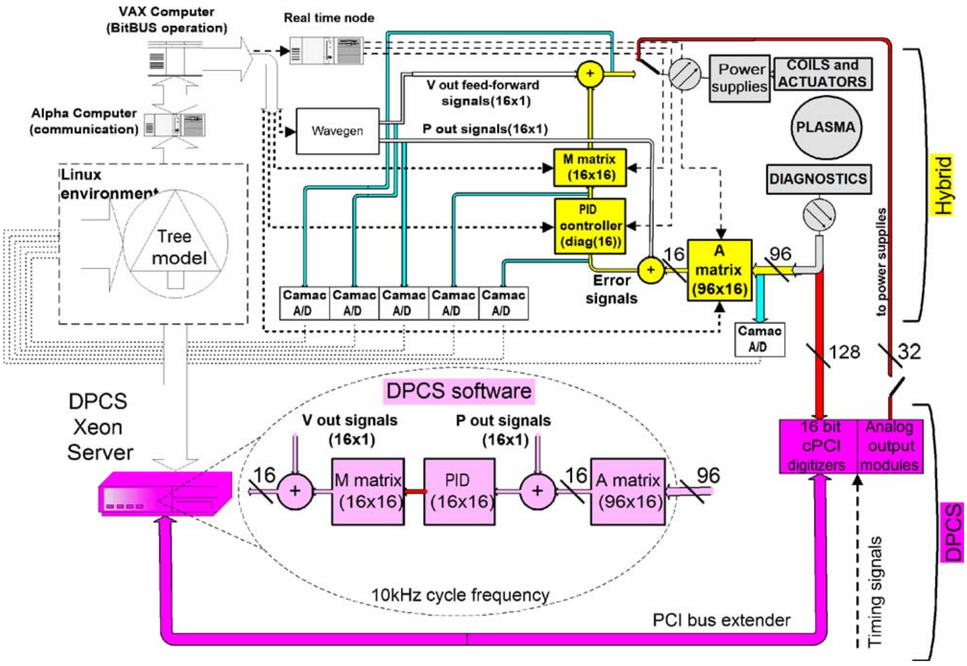

Fig. 1. Alcator C-Mod control system. Hybrid Digital/Analog computer (top). All-digital system (bottom).

digital-analog control system [2] was designed and implemented in conjunction with the group from the TCV tokamak from EPFL in Switzerland, with the hardware implemented by EPFL [3] and the software developed at MIT. The system proved stable and reliable in its 14 years of operation, but maintenance issues and the need for a more flexible platform have led us to build a replacement DPCS. The first requirement for the new control system was that it must function as a drop-in replacement for the original system. Fig. 1 shows both the hybrid and the new digital systems as a block diagram. The steps of the control loop, in both cases, are

- The diagnostics provide information on the magnetic field inside the machine and on the plasma.
- The multiplication by the time dependent 'A' matrix (96 inputs × 16 outputs) computes the 'observers', that is the 16 physical quantities of interest.
- The pre-programmed target waveforms are subtracted from the observers.
- The PID controllers act on the error signals with time dependent gains.
- The controller matrix ('M') is multiplied by the output of the PID to produce the correct action on the relevant actuators, and 16 pre-programmed feed-forward waveforms are added. This allows for both open and closed loop control signals, and reduces the needed gains in the PID feedback stage.

The hybrid's analog outputs as well as the values of the intermediate steps in the computation are digitized using CAMAC for use in debugging and diagnosis of the control system operation. Care must be taken that hybrid computed values stay within the hardware voltage ranges throughout all of the steps of the computation. The real-time node (INTEL 8044) plays out pre-programmed scenarios, stepping the waveforms and matrices through their programmed values. In the hybrid, digitally programmed analog circuits perform the matrix operations and produce the feedback signals. There are also provisions in the hardware for adaptive control, but the difficulties and risks of programming and debugging the real-time computer in 8044 assembler prevented us from pursuing it.

Communication between the data system computers and the hybrid control computer was done over a bitbus