Control and Data Acquisition System for Lower Hybrid Current Drive in Alcator C-Mod

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Abstract. A lower hybrid current drive (LHCD) system is being installed on the Alcator C-Mod tokamak. Initially, 12 klystrons operating at 4.6 GHz will deliver a total power of 3 MW to the coupler. The LHCD system will make it possible to modify the current density profile in the outer half of the plasma. This implies that the q-profile can be manipulated, thereby enabling the study of advanced tokamak regimes. In this paper we describe the overall structure of the control and data acquisition system for LHCD. The acquisition setup collects data from the active controller, the transmitter protection and the coupler protection systems. Long pulse tests of the klystrons are presented and a monitor camera is introduced.

INTRODUCTION

Active control of the current density profile has been shown to enable the attainment of advanced tokamak operation in several magnetic confinement devices (see Ref. [1] and references therein). This has motivated the installation of a lower hybrid current drive (LHCD) system on the Alcator C-Mod tokamak [2, 3]. A combined model for current profile control and magnetohydrodynamic stability analysis has identified stable operating modes for $\beta_N \simeq 3$ and a high bootstrap current fraction f_{BS} = 0.70 [4]. For this scenario, the q-profile is controlled by LHCD in the outer half of the plasma, resulting in a non-monotonic q-profile, where $q_{min} > 2$.

The LHCD system on Alcator C-Mod will initially consist of 12 klystrons operating at 4.6 GHz, supplying a total of 3 MW to a single coupler. In the second phase, 4 klystrons and a second coupler will be added. A schematic view of the coupler is shown in Fig. 1. The plasma position is indicated on the left-hand side, the coupler on the right-hand side. Note the 3 dB divider forming an 'X' close to the center of the coupler. The construction of the LHCD system is a collaboration between Princeton Plasma Physics Laboratory (PPPL) and MIT. PPPL is responsible for the front-end of the system (grill, waveguide run); status of that part of the hardware can be found in Ref. [5].

CONTROL SOFTWARE

The LHCD control software is made up of two separate parts: The operator system (OS) and an active controller system (ACS). The ACS has been described in Ref. [6], so we

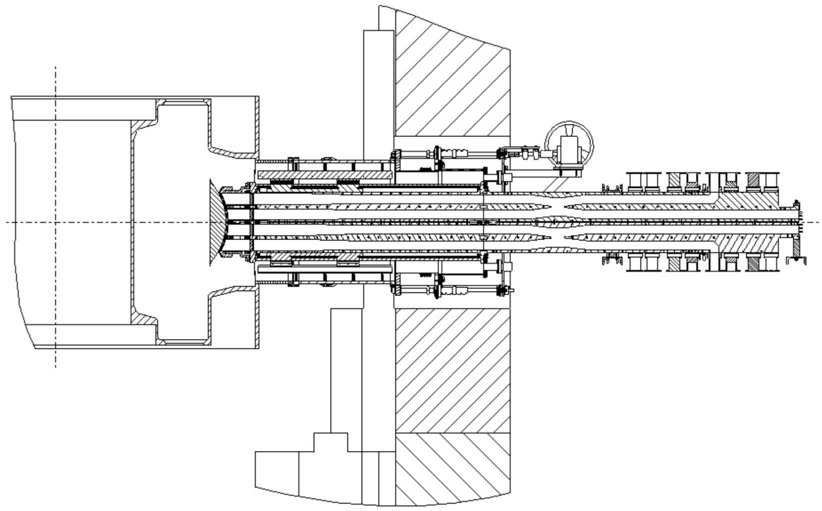

FIGURE 1. Side view of the coupler, taken from [5].

focus on the OS. This has 4 main purposes:

- To construct amplitude and phase waveforms for the klystrons
- To establish the timing sequence
- To acquire raw data
- To calibrate raw data

The main component of the OS is a graphical user interface made using the interactive data language (IDL) running on a Linux platform. It is called the lower hybrid control system (LHCOSY); a preliminary version of the main panel is shown in Fig. 2. The 'RF gate' is controlled from the left-hand column and determines the start time and duration of the klystron pulse. The RF gate is displayed in the central column. Amplitudes and phases supplied to the klystrons can be altered by clicking on the buttons above the RF gate plot (this opens new widgets). Below the plot, timing information can be viewed and modified. The timing information - along with amplitudes, phases and other data - is written to the Alcator C-Mod MDSplus tree. The timing gates are transferred to Jorway 221 modules, which in turn sends the signals to the klystron systems and the ACS. A number of options in LHCOSY makes it easy to re-use waveforms and other settings from previous discharges or test shots. The status of LHCOSY is that all main features are implemented, except the treatment of calibrations.

DATA ACQUISITION AND KLYSTRON TESTS

Data acquisition (and calibration, when completed) is done through the MDSplus tree. The data acquisition hardware consists of a number of compact PCI (cPCI) modules, each sampling 32 channels at 250 kHz with 16 bit resolution [7]. Data is acquired both

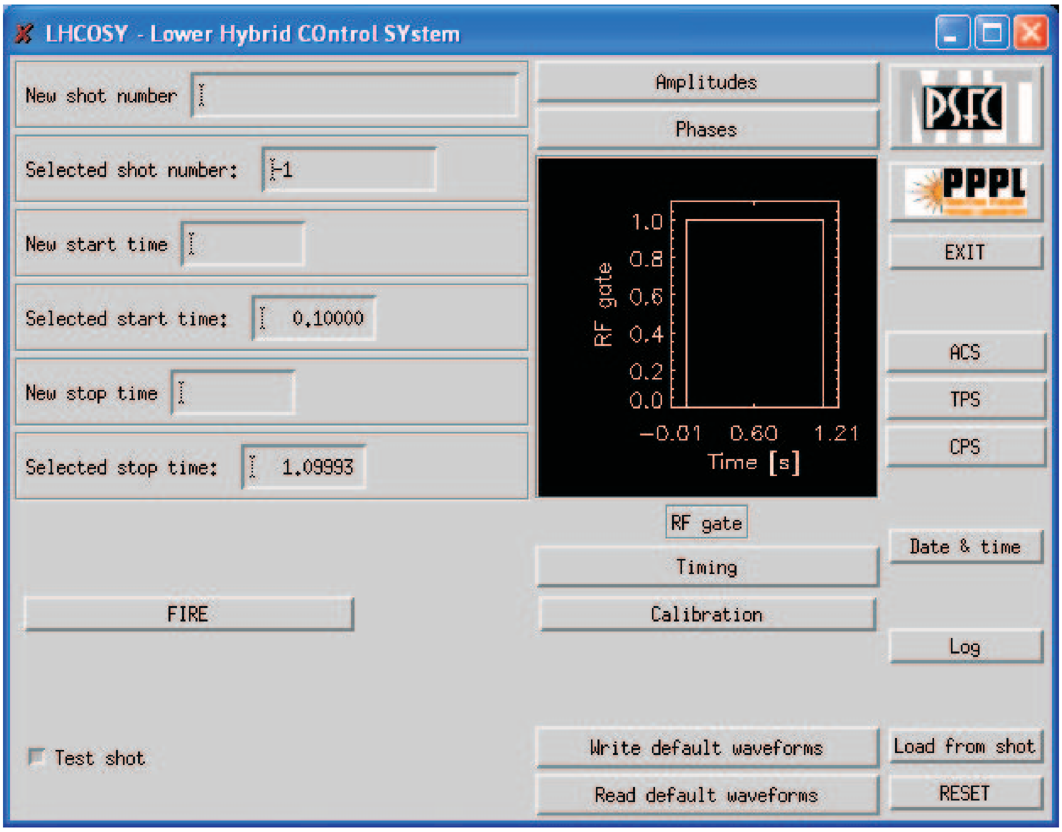

FIGURE 2. Main panel of the lower hybrid control system (LHCOSY).

from the ACS and from the transmitter (TPS) and coupler (CPS) protection systems. The measurements can be viewed either through LHCOSY (from buttons in the right-hand column, see Fig. 2) or using scopes, an MDSplus plotting utility.

To illustrate some of our first results using the cPCI system, we discuss measurements made of TPS signals. These measurements were conducted to test the high voltage power supply and the klystrons [8]. The klystrons are mounted on 3 carts, 4 klystrons on each one; in Fig. 3, we show waveforms from test shot 138. Here, we tested klystron 4 on cart 2 for long pulse, high power operation: The discharge lasted 1 second and the forward power (2nd trace from top) was 256 kW (rating: 250 kW). The body current settled at 20 mA (bottom trace). All 12 klystrons have now been successfully tested for long pulse, high power usage. Note that only voltage measurements are shown in Fig. 3, the calibration part of the software is not yet complete.

The CPS will be used to monitor and protect the waveguide run, for phase calibration purposes and to measure the coupling to the plasma. Since the coupling efficiency is affected by density fluctuations, the CPS detectors will indirectly measure those fluctuations. Therefore we have ordered a 16 channel fast (10 MHz sampling rate) cPCI board to be able to study high frequency density fluctuations in front of the grill.

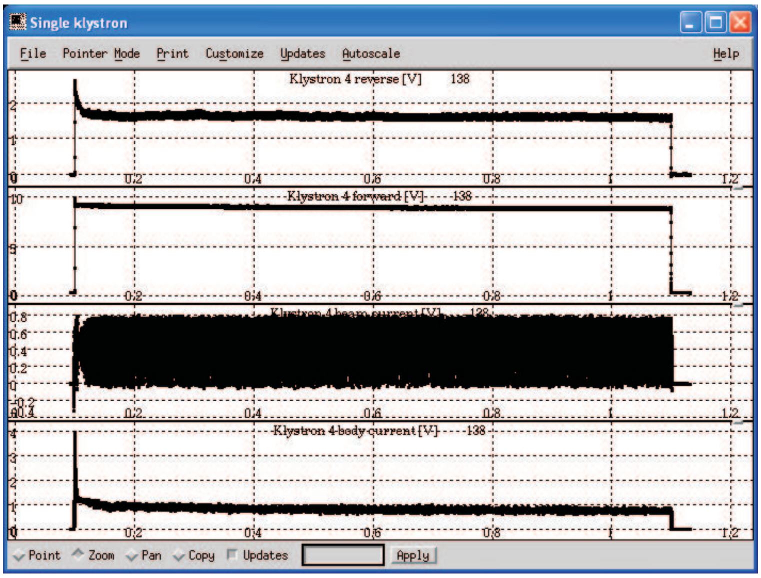

FIGURE 3. Waveforms from a long pulse test of a klystron, top to bottom: Reverse power, forward power, beam current and body current.

MONITOR CAMERA

An important diagnostic in the initial phase of LHCD operation will be a camera. This will allow us to monitor the occurrence of e.g. arcs at the grill. A camera observing a limiter is already installed in a port from where the grill can be viewed. Since this camera will be used alternately for observing the limiter and the grill, we only needed to design and machine a modified camera holder. This has now been done, and the view will be tested during the current Alcator C-Mod campaign. The camera is mounted in a re-entrant port, allowing us to change the camera holder without breaking vacuum.

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