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Control System for the Lithium Beam Edge Plasma Current Density Diagnostic on the DIII–D Tokamak

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Abstract. An edge plasma current density diagnostic employing a neutralized lithium ion beam system has been installed on the DIII–D tokamak. The lithium beam control system is designed around a GE Fanuc 90–30 series PLC and Cimplicity® HMI (Human Machine Interface) software. The control system operates and supervises a collection of commercial and in-house designed high voltage power supplies for beam acceleration and focusing, filament and bias power supplies for ion creation, neutralization, vacuum, triggering, and safety interlocks. This paper provides an overview of the control system, while highlighting innovative aspects including its remote operation, pulsed source heating and pulsed neutralizer heating, optimizing beam regulation, and beam ramping, ending with a discussion of its performance.

I. INTRODUCTION

The lithium beam diagnostic on the DIII–D tokamak has been designed to make precise measurements of the magnitude and shape of the edge current density [1]. The recent development of the magnetohydrodynamic (MHD) stability code (ELITE) [2], [3] shows the importance of MHD stability in control of the plasma edge, and can be used to further improve advanced tokamak (AT) mode performance. One factor currently limiting ELITE is the lack of experimental plasma edge current density data.

The components to the lithium beam diagnostic can be broken down into four major parts: beam line, control system, optical system, and data acquisition system. An overview of the beam line and control system will be given, along with examination of the following control aspects: remote operation, pulsed source heating, pulsed neutralizer heating, beam ramping, beam modulating and optimizing beam regulation.

II. SYSTEM OVERVIEW

The lithium beam-line consists of an ion source, source heating filament, accelerator, suppressor, Einzel lens, deflector plates, and sodium vapor neutralizer (Fig. 1). The ion source is made from the thermoemissive glass β-eucryptite, deposited onto a 5 cm diameter sintered tungsten sponge. A tungsten filament, dropping 20 VAC and passing 20 A, is located behind the source (Fig. 2). Biased at 1300 VDC relative to the source, the filament electron-heats the source to 1200°C, releasing Li^6 ions with extremely low (~0.1 eV) intrinsic ion temperatures. With the implementation of pulsed source heating, described later, the sources typically last more than a thousand 10s shots before needing recoating. The lithium ions are accelerated to 30 keV while a suppressor biased at 1.5 kV

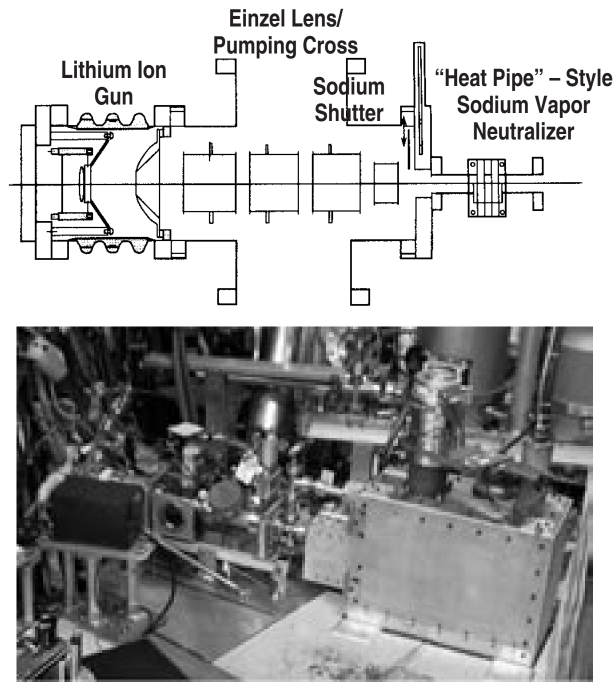

Fig. 1. Above, the DIII–D lithium beam's lithium ion gun and accelerator, electrostatic lens, and sodium vapor neutralizer, all enclosed behind magnetic shielding (below at right), seen as installed on the DIII–D tokamak at General Atomics.

prevents electrons from backstreaming towards the source. The beam is then electrostatically focused using an Einzel lens to a diameter of 1cm and steered using deflector plates before entering the neutralizer region. The ions are neutralized in a sodium vapor in as short a distance as possible in order to minimize space charge effects and neutral beam spreading.

The control system is comprised of a series of high voltage power supplies, power supply controllers, a neutralizer controller, PLC and remote computer system (Fig. 3). Five commercial, high voltage Glassman power supplies are used: +30 kV for acceleration, +30 kV for lensing, –3 kV for the suppressor, and ± 3 kV for the two deflector plates. Power for filament heating and biasing comes from two transformer/rectifier linear power supplies, employing a GA designed controller [4]. Current feedback is used to regulate both the filament and bias power supplies due to the highly nonlinear thermal resistivity of the filament and the nonlinear nature of electron heating. Both power supplies utilize the principle of AC voltage phase control to precisely "chop" the input AC

Fig. 2. Lithium source flange showing spiral tungsten filament and tantalum heat shielding. The filament, biased –1300 VDC below the lithium source (seen at right), electron heats the source to 1200ºC.

voltage. The phase controller references AC phase information from the AC line which provides load power. However, an interesting instability was found when the isolation transformer's secondary winding (isolating the 120 V line voltage from 30 kV the filament and biasing circuitry float at) would distort when heating with high bias current. The combination of transformer reactance and inrush current demanded by the power supply resulted in harmonic distortion of the AC waveform. Coupled with the load's characteristics, this caused the phase controller to go unstable and break into oscillation. The solution was to install a separate, small (50 VA) 50 kV isolation transformer to couple distortion-free primary power AC phase information to the controller.

A 90/30 series PLC is used to monitor all safety interlocks, control and enable all power supplies and sub controllers, give system status readback, process ion gauge control, and trigger and timing of the ion beam. The PLC employs digital input and output modules for discrete logic handling, and analog input and output modules for analog sensing and power supply program control. All logic functions were coded in the PLC using ladder logic via Versapro software from GE Fanuc. To graphically interface users to the control system Cimplicity Plant Edition software, also from GE Fanuc, was used. Using Cimplicty, a GUI was programmed to the needs and functions of the lithium beam system (Fig. 4).

III. CONTROL SYSTEM HIGHLIGHTS

The lithium beam control system was designed to be flexible and expandable for future needs. Remote operation of the system was a requirement due to its inaccessibility when running plasma experiments. All control components minus the PC computer in direct exposure to radiation. For voltage isolation protection, a fiber optic ethernet connection is used from the system's PLC in the tokamak area to a remote location behind radiation shielding. For even greater flexibility, Cimplicity and the computer system was configured as a web server with password protection. This

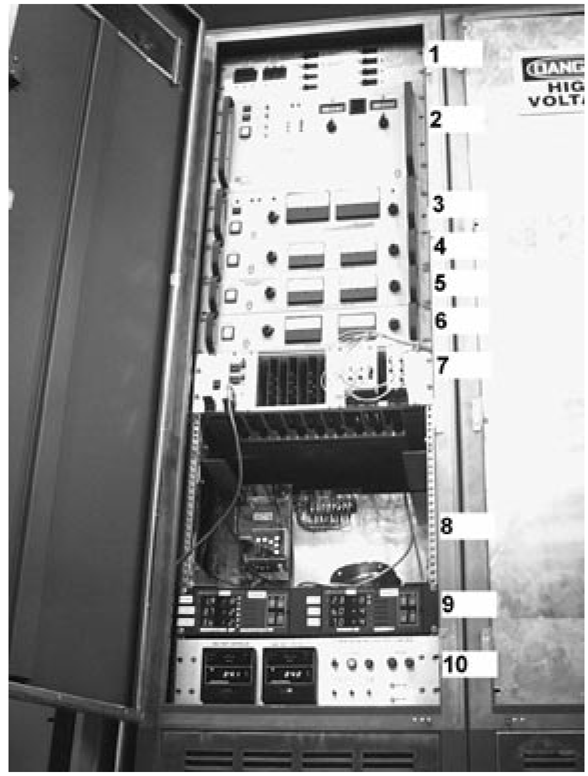

Fig. 3. The lithium beam control rack consists of (1) breaker panel, power supplies (2–6) +30 kV accelerator, +30 kV lens, ± 3 kV deflector plates, +3 kV suppressor, (7) crate for timing receiver and fiber optic communications to "hot deck" (the right hand cabinet containing filament and bias power supplies and their feedback controllers, all floating at the +30 kV accelerating potential), (8) PLC (on reverse side; not seen here), (9) ion gauge controller, and (10) sodium neutralizer controller.

allows control of the diagnostic from anywhere in the facility, allowing scientists to monitor and change beam parameters from the operations control room or their own offices. For collaboration purposes, modifications are currently being made to expand control to anywhere off-site as well.

In efforts to extend the life of the ion source, a ramp up and pulsed heating method is used. Upon command a filament power setting, the PLC ramps up the current thru the filament in a controlled manner to prevent thermal shock. During normal operation, the filament and bias supplies idle at a constant power. Three minutes before the plasma shot occurs, a DIII–D initiated asynchronys trigger is sent to our timing chassis. This signal is detected by the PLC and initiates a command to the bias power supply, raising its output power to a predetermined high heat setting. After the lithium beam has fired, the bias returns to it's idle, low heat setting, readying itself for the next shot. Pulsed heating has allowed a single source to last for an entire year of operations.

A similar pulsed heating system is used for the sodium neutralizer control. In the past, the neutralizer was left in a high heat state for each full day of operation. Though a mechanical shutter is present to hinder efflux of sodium throughout accelerator chamber, sodium deposition in this area

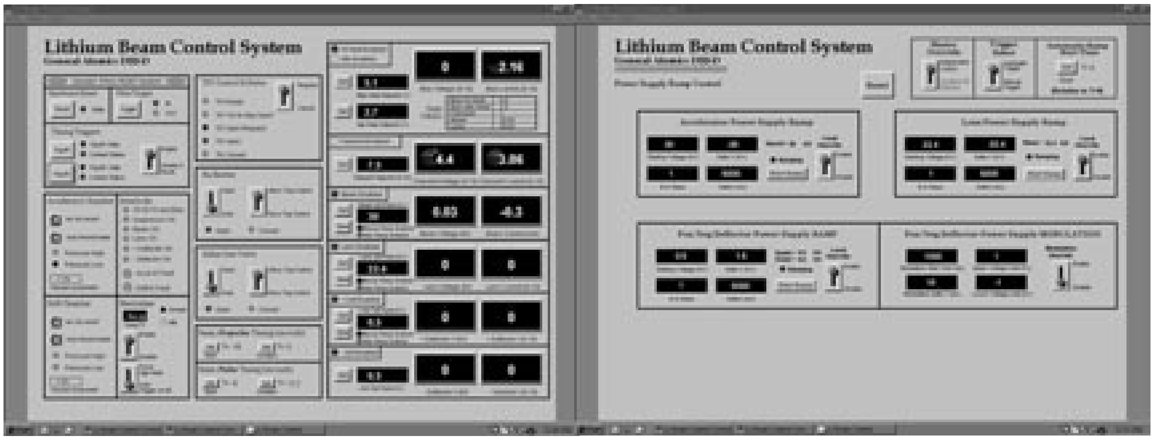

Fig. 4. Programming using GE Fanuc's Cimplicity HMI software, above is the main lithium beam control screen, and below is the power supply ramp and modulation control screen.

was found to be high. In order to minimize this and prolong the life of the sodium, two Omega temperature controllers are used to regulate the temperature of the sodium heat pipe: one for the low idle heat setting (210°C) and one for the high heat setting (295°C). The PLC commands which temperature controller takes precedence, again based on DIII–D timing triggers. Due to the steep vapor pressure curve of sodium in this temperature region, this small change (~100°C) in temperature greatly effects the sodium boil-off. During the last vent, it was noted that the sodium accumulation in the lithium beam line was dramatically reduced when compared to non-pulsed heating of the neutralizer.

The PLC has also been programmed to allow the ramping of the accelerating, lensing, and deflector plate potentials. During initial installation and calibration of the new 32 channel optical system [5], it was found that tuning of the etalons and optimizing beam quality was best done by sweeping the lithium beam in various parameters. By ramping the accelerating potential, the optimal beam energy can be found, by ramping the lens potential, beam quality can be optimized, and by ramping the deflector plates, beam centering can be adjusted. By temporally comparing these parameters with lithium beam spectral data, the parameters can be quantitatively found and set for subsequent experiments. Currently, a design for modulating the deflector plates at a frequency up to 2.5 kHz is underway. The goal is to 'chop' the beam in and out of the plasma electrostatically rather than mechanically. The reason for this is when using the diagnostic to measure the edge of H–mode plasmas, tiny errors in the background affect the implication of the measurement. Thus, by effectively turning the beam on and off, real-time subtraction of the background content is possible, thus lowering the uncertainty of measurement.

Beam regulation is also of great concern. The limiting factor in spectral resolution is no longer the optical system, but the beam energy regulation. The desired regulation is 0.003%, or 1 Vpp out of 30 kV. The beam ripple is presently between 2–4 Vpp depending on conditions, lowered from a previous 250 Vpp. We hope to reduce this ripple by a another factor of 0.25 via closed loop control coupled to a piggy back supply.

IV. CONCLUSION

The lithium beam plasma edge diagnostic is a source for near real-time data of the edge current density. With it, improvements of plasma performance and stability can be gained. The lithium beam diagnostic on the DIII–D tokamak has successfully made localized measurements of the magnetic field components (and thus current density thru Ampere's law) in the desired region for comparison with edge stability models. The diagnostic's control system is completely remote, and has such features as pulsed source and neutralizer heating for extended, long life operation, beam parameter ramping for beam quality and optics optimization, tight beam power regulation, and future designs for beam modulating and enhanced beam regulation.

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