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The DIII-D E||B charge exchange diagnostic

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One of the neutral-particle spectrometers used on the Doublet III tokamak has been improved and modified for use as an active charge exchange diagnostic on the DIII-D tokamak. The spectrometer employs a He stripping cell, parallel E and B analyzer fields, and a microchannel-plate detector with 60 energy channels for each of two neutral-particle masses. Improvements to the diagnostic include better radio frequency and γ-ray shielding and complete instrumentation of all energy channels. Calibration results for H and D are similar to those reported previously. The instrument views across one of the DIII-D heating beams which can be modulated to provide local neutral doping. The analyzer is scanned shot to shot to measure neutrals with pitch angles between $\sim 5°$ and $\sim 110°$.

INTRODUCTION

One of the charge exchange diagnostics[1] used on the Doublet III tokamak has been adapted for use on DIII-D.[2] In this article, we document modifications to the previous instrument (Sec. I) and describe the calibration of the modified spectrometer (Sec. II). The article concludes with a summary of anticipated applications (Sec. III).

I. MODIFICATIONS TO THE DIII DIAGNOSTIC

The spectrometer selected for installation on DIII-D is the "T-perpendicular" charge exchange diagnostic used on Doublet III. This instrument[1] is a multichannel, mass-discriminating spectrometer that employs parallel E and B analyzer fields. After ionization in a stripping cell, incident neutrals circle 180° with a Larmor radius determined by the B field (momentum analysis); simultaneously, the applied electric field causes a drift perpendicular to the gyromotion that is proportional to the mass of the incident neutral. The unique feature of our E||B spectrometer is a microchannel-plate detector set at an angle of 47.5° to the exit face of the magnet. This canted detector plane linearizes the columns of each mass, which simplifies the detector design and permits the magnet gap to be only 1.3 cm wide. The narrow gap minimizes fringe field effects on particle trajectories.

The analyzer section has only undergone slight modifications from the previous design. Except for a slight repositioning of the field coils to permit easier microchannel-plate installation, the geometry of the ANAC[3] magnet was unchanged. The insulation of the pole pieces was also improved to permit operation at bias voltages up to 1 kV. The yoke is capable of operation without saturation at fields up to 6 kG, which suffices to bend 100-keV deuterons in the 26-cm-diam pole piece. Because of its relatively small gap, the magnet can be operated with a relatively modest power supply[4] and cooling system.[5] The magnetic current is controlled by an ANAC[3] Hall probe, which was cross calibrated to 1% by a calibrated gaussmeter.[6] Provision has been made to reverse the sign of the electric field between data-acquisition clock pulses (using a Sorensen[7] power supply and a homemade switching module) so the background can be measured dynamically during a plasma discharge. As on Doublet III, three layers of magnetic shielding are employed. The thickness of the outer soft iron shield plates has been increased to 1.3 cm to avoid saturation in the larger stray fields produced by DIII-D.

The He stripping cell is unchanged from Doublet III. The gas controller has been replaced by an MKS baratron and piezovalve controller[8] that give stable pressures of ~ 10 μ in the cell within 30 s.

The microchannel-plate (MCP) assembly[9] is a special Z plate assembly manufactured by Galileo Electro-Optics Company.[10] The plate has two 1.0-cm-wide columns of 60 anodes each; each anode is 0.5 cm long (in the energy direction). Essentially, the MCP hardware is unchanged from Doublet III. The grounded 90% transparent mesh that shields the front surface of the detector was replaced with a less fragile mesh[11] and the cabling to the discriminator modules was shortened to give greater pulse heights and reduced reflections. These cables now consist of an ~ 100-cm length of 100-Ω coaxial cables,[12] followed by an ~ 20-cm length of 75-Ω cable that terminates in 50 Ω at the discriminator modules. The operation of the MCP is discussed in Sec. II.

On Doublet III, oil from the vacuum pumping system was observed on the MCP. In our reconfigured vacuum system, the spectrometer chamber is still pumped by a 2000-ℓ/s (helium) Balzers turbomolecular pump,[13] but the pump is now situated behind a gate valve that isolates the spectrometer chamber during loss of vacuum.

The apparatus is mounted on a cart and connected to the DIII-D vacuum vessel by welded bellows[14] (Fig. 1). The cart position is remotely controlled to an accuracy of $\sim 0.1\%$ by an Origa actuator.[15] The position of the cart was related to the angle of observation by shining a HeNe laser through the stripping cell into the tokamak and making a series of measurements of the location of the beam inside the vacuum vessel. The sightline of the instrument is ~ 10 cm above the horizontal midplane and can be varied from $R_{\tan} \simeq 232$ cm in the co-circulating direction to $R_{\tan} \simeq 41$ cm in the counter-circulating direction (Fig. 2).

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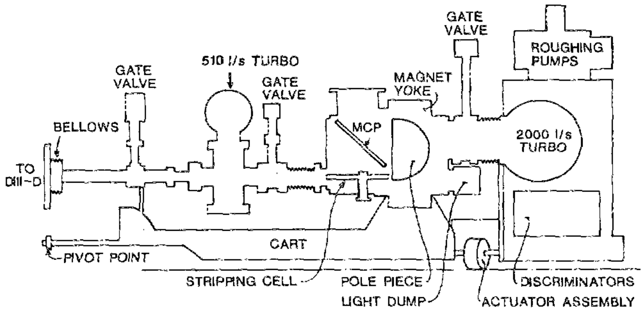

FIG. 1. Elevation of the diagnostic.

On Doublet III, hard-x-ray bremsstrahlung produced by runaway electron collisions with the tokamak limiter often contaminated the data. In the new diagnostic installation, the apparatus is no longer in the forward cone of the hard-x-ray beam, so this source of spurious signal is not expected to be a problem. Nevertheless, provision to enclose the spectrometer with 10-cm-thick lead shields was included in the design. A new source of noise anticipated on DIII-D is electrical pickup associated with intense radio-frequency heating. To protect the instrument from rf, the power supplies and data-acquisition modules are mounted in an air-conditioned,[16] shielded electronic enclosure[17] and all cables connecting the spectrometer to this "rf rack" are well shielded. The vacuum pumps, gauges, and controllers are excluded from this shielded enclosure. Power lines and external signals pass through low-pass filters.

The instrumentation for data acquisition and computer control have been extensively modified (Fig. 3). Pulses from the MCP are counted by a set of eight 16-channel discriminators manufactured by Phillips Scientific.[18] The discriminators are housed in a rf-shielded CAMAC crate that is mounted directly behind the spectrometer. Each discriminator module is connected by a ribbon cable to a pair of LeCroy scalers[19] and an associated 64K memory module.[20] Clock pulses are controlled by a Jorway clock.[21] After a tokamak discharge, data are transferred through a fiber-optic serial highway to a dedicated MicroVAX II computer.[22] Hardware for communication between the computer and the CAMAC modules consists of a serial highway driver,[23] L2 crate controllers,[24] and U Port adapters[24,25] from Kinetic Systems; software utilizes the interface program written at ORNL.[26] Between tokamak shots, the MicroVAX prepares plots of raw data and sends data via a Q bus[22] to a VAX cluster[22] for subsequent, more extensive, analysis. Spectrometer fields, gas pressure, and vacuum status are computer controlled through DAC,[27] ADC,[28] output register,[29] and contact sense[30] modules. Protective interlocks are supplied by a standalone programmable logic controller.[31]

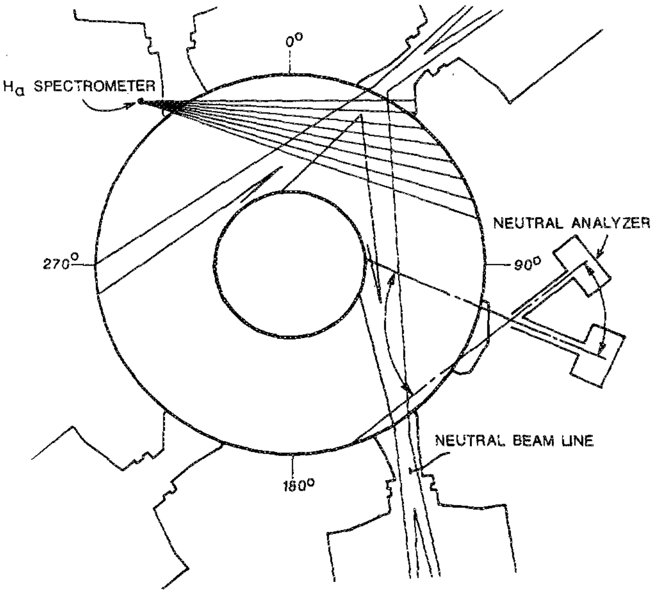

FIG. 2. Plan view of the DIII-D tokamak (major radius ≃167 cm; minor radius ≃67 cm) showing the apparatus for beam-ion profile measurements. Each neutral beam line contains two ~1.5-MW, ~80-kV beam sources.

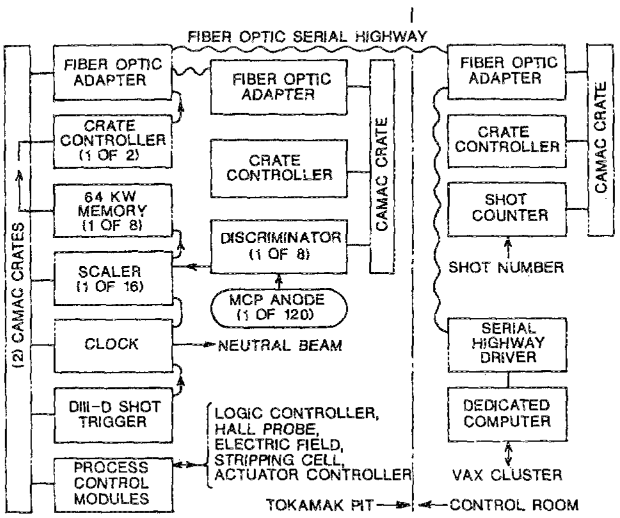

FIG. 3. Block diagram of the computer and CAMAC configuration.

II. CALIBRATION

The spectrometer was calibrated using the General Ionex ion accelerator[32] used previously.[1] An ideal calibration source would supply a monoenergetic beam that simulates the plasma geometry by irradiating uniformly the spectrometer at all angles of incidence. In practice, the cross-sectional area of our beam was adequate (i.e., larger than the entrance aperture of the stripping cell) but the angular divergence of the beam was less than the angular acceptance of the cell (the beam was more collimated than the plasma). This implies that the actual resolution of the spectrometer could be somewhat worse than inferred from our measurements. A second difficulty is that, due to collisions in the extractor section of the accelerator, our beam often was not monoenergetic. Beam behavior was monitored with a Channeltron[10] or a PIPS[33] detector mounted in a straight-through port (with the light dump removed). The beam profile was studied by translating these detectors horizontally across the beam. The results are consistent with uniform illumination of the entrance aperture of the stripping cell. For beam energies $\gtrsim 40$ kV, it was possible to make absolute measurements of the incident flux with the PIPS detector. Below ~40 kV, detector noise precluded accurate pulse counting. The Channeltron detector was useful for relative measurements in the lower energy range; however, with our experimental configuration, the Channeltron did not measure the total incident flux so absolute measurements below ~40 kV were impossible. The energy of the beam was measured with the PIPS detector and used to ensure that the desired energy and species were obtained from the accelerator.

The initial stage of the calibration was to establish optimal settings for the MCP bias voltage and discriminator thresholds. The signal shape and pulse-height distribution from the MCP (Fig. 4) permit accurate pulse counting with good noise rejection. Settings of $V_{\text{bias}} = 2700$ V and $V_{\text{thresh}} = 100$ mV were selected for normal operation.

The position of the ion beam along the MCP is governed by the ion Larmor radius[1] for H, D, and He beams. The typical energy resolution is 5%.

Beam steering across the gap approximately follows the mV_{gap}/B^2 scaling (independent of energy) found previously.[1] Although the centroid of the beam behaves as expected, the mass resolution is poorer than calculated by Armentrout *et al.*[1] Typically, when V_{gap} is adjusted to simultaneously measure H and D, only about 97% of the unwanted species is rejected.

III. APPLICATIONS

The principal anticipated application for the diagnostic is to measure the spatial distribution of beam ions. The sightline of the analyzer is scanned shot to shot across the 150° neutral-heating beam (Fig. 2). The beam is modulated to identify the signal from the actively doped region. The neutral profile of the beam is measured with the tangentially viewing CER diagnostic[34] tuned to the H_α line (assuming the deposition of the 30° and 150° heating beams are similar). The ratio of active signal to neutral density yields the beam-ion density at the energy and pitch angle of observation.

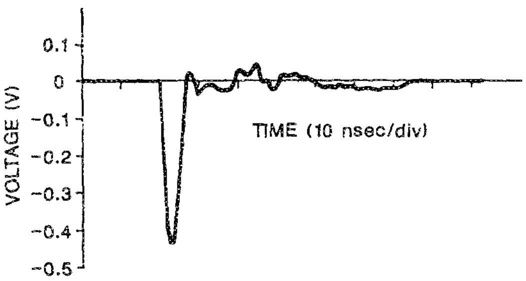

FIG. 4. Pulses from a MCP anode measured at the input to the discriminator. $V_{\text{bias}} = 2700$ V. The shape of the pulse spectrum is similar to the one given in Fig. 9 of Ref. 9.

The mass discrimination is inadequate for simultaneous hydrogen beam slowing-down measurements and deuterium ion temperature measurements during $H^0 \rightarrow D^+$ neutral beam heating. Ion temperature profiles will be possible under some conditions, however. Spectral measurements during ion wave heating are another important application.

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[5] 750 Exchanger from GTE Sylvania.

[6] Model 811 Digital Gaussmeter from F. W. Bell Inc., Orlando, FL 32807.

[7] DCR 600-.75B from Sorensen Co., Manchester, NH 03103.

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[11] 30 lpi 90% transparent Ni mesh from Buckbee Mears Co., St. Paul, MN.

[12] CXN 145 from W. L. Gore and Associates, Inc., Newark, DE 19711.

[13] Balzers, Hudson, NH 03051.

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[15] 50 series Electric Cylinder and 4800C Controller from Origa Corp., Elmhurst, IL 60126.

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[19] LeCroy Research Systems Corp. 8590M, Spring Valley, NY 10977.

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