Recent Developments on the High Power ECH Installation at the DIII–D Tokamak

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The 110 GHz gyrotron installation on the DIII–D tokamak has been incorporated into the experimental program as a research tool while in parallel being further characterized and upgraded. Two gyrotrons are in regular operation and a third is in testing. The first gyrotron is a Gycom ‘‘Centaur’’ model, which has reliably generated more than 800 kW for two second pulse lengths. The second gyrotron is a CPI VGT-8011A, which has regularly generated 750 kW at one second pulse length and has been tested at up to 1.09 MW for 600 ms pulse lengths.

These gyrotrons, operating both modulated and cw, have been used in power deposition profile measurements, transport studies, measurements of electron cyclotron current drive, heating, H–mode studies and magnetohydrodynamic mode stabilization. Using two different launchers, one injecting with a toroidal component and the other perpendicular to the magnetic field, comparisons between heating plus current drive and heating only were made to enhance the accuracy of the measurement of the electron cyclotron current drive. Changing the poloidal angle of the final launcher mirror permits the rf beam to be steered anywhere in the tokamak upper half plane and this feature, coupled with changes in the tokamak toroidal magnetic field, has been used in studies of off-axis electron cyclotron current drive, which is an essential element of advanced tokamak operation leading to reactor-relevant regimes of operation for modest sized tokamak devices.

Several experimental results have been obtained thus far. Injection of 1 MW of rf power into DIII–D yielded a DIII–D record electron temperature of 10 keV at low density. The direct measurement of transport coefficients in the electron channel using modulated rf gave a check on the internal self consistency of transport calculations based on equilibrium kinetic profiles. Another of the highest priority experiments has been the verification of theoretical calculations of electron cyclotron current drive efficiency. To date, analysis indicates that electron cyclotron wave driven currents greater than 100 kA at an efficiency of 0.03×10^{20} A/W-m^2 have been achieved. This is comparable to the fast wave current drive efficiency near the ion cyclotron resonance frequency. Engineering tests of the polarization and power deposition profiles showed that 100% X–mode could be generated for any plasma configuration, both for oblique and perpendicular injection and that the power deposition was consistent with the spatial cross section of the beam for pure X–mode.

The high power, long pulse operation of the CPI gyrotron at DIII–D was at the same parameters that had been used during initial testing at CPI for shorter pulses [1], and, except for output window heating, there was no indication that longer pulses could not have been generated. The Gycom gyrotron has been extremely reliable for more than a year and can generate two second pulses whenever required without compromising the output power. The transmission lines for both tubes are evacuated windowless step-corrugated circular waveguides carrying the $HE_{1,1}$ mode and launching a Gaussian beam into the DIII–D tokamak. About 75% of the rf power passing through the gyrotron windows for both systems is injected into DIII–D.

For studying the gyrotron performance, a rotating polarimeter was developed which is capable of performing direct beam polarization measurements in the evacuated waveguide for high power and long pulses. This instrument was also used to characterize the performance of remotely controllable vacuum compatible polarizing miter bends, which permit producing the proper ellipticity and tilt angle to generate the desired X–mode for any plasma configuration, resulting in optimization of the single pass absorption of the injected rf beam.

Measurements of the gyrotron current-voltage characteristics for the Gycom and CPI gyrotrons were made to understand cathode performance leading to an understanding of parasitic emission from the Gycom tube at 96 MHz.

A third gyrotron, also built by CPI, using a diamond disk output window and generating a Gaussian beam, has been installed at DIII–D and is being tested. At the time of this writing, this tube was generating 350 kW in a pulsed regime for mode mapping studies at the CPI facility. High power tests of the diamond window disk and thermal calculations indicate that this gyrotron should be capable of generating substantially longer pulses at one megawatt than have heretofore been achieved.

A description of the system will be presented and the results of the tokamak experiments to date will be summarized. Measurements and analysis of the gyrotron performance, including the beam polarization, and the first report of the operational experience with the diamond window gyrotron will be discussed. DIII–D has committed to a further upgrade of the electron cyclotron heating system as a part of the advanced tokamak research program and these plans will be presented.

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[1] Kevin Felch *et al.*, IEEE Transactions on Plasma Science **24**, 558 (1996).