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Initial Results from the Multi-Megawatt 110 GHz ECH System for the DIII-D Tokamak

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Abstract. The first of three MW-level 110 GHz gyrotrons was operated into the DIII–D tokamak in late 1996. Two additional units will be commissioned during 1997. Each gyrotron is connected to the tokamak by a low loss, windowless, evacuated transmission line using circular corrugated waveguide carrying the HE_{11} mode. The microwave beam spot is well focused with a spot size of approximately 6 cm and can be steered poloidally from the center to the outer edge of the plasma. The initial operation with about 0.5 MW delivered to a low density plasma for 0.5 s showed good central electron heating, with peak temperature in excess of 10 keV. The injection was 19° off perpendicular for current drive.

INTRODUCTION

To support the Advanced Tokamak (AT) regimes in the DIII–D tokamak, methods are being developed to control the current and pressure profiles across the plasma discharge. In particular, AT plasmas require substantial off-axis current in contrast to normal tokamak discharges where the current peaks on-axis. At present AT plasmas can only be produced transiently because there is no means of driving off-axis currents. An effort is under way to use Electron Cyclotron Current Drive (ECCD) as a method of sustaining the off-axis current in AT plasmas. The first phase of this system is the installation of three megawatts of electron cyclotron heating power. This involves the installation of three gyrotron systems operating at 110 GHz, the second harmonic resonance frequency on DIII-D, with each system generating nominally 1 MW for two seconds or less. The three systems will use one GYCOM [1] (Russian) gyrotron and two CPI [2] (formerly Varian) gyrotrons, all with windowless evacuated corrugated low loss transmission lines. The GYCOM gyrotron system has been tested at the factory and installed at DIII–D [3], and to-date over 500 kW of rf power has been injected into DIII–D plasmas on a routine basis for 500 ms. This paper describes the

Electron Cyclotron Heating (ECH) systems and reports on the results of the tests using the GYCOM gyrotron.

ECH SYSTEM OVERVIEW

The entire transmission line system consists of six mitre bends and is ≈ 40 m long with estimated 2% loss in the waveguide and 0.6% loss per mitre bend. The mitre bend losses are from mode conversion 0.5% and ohmic losses 0.1%. The waveguide is evacuated to a pressure of $\approx 1\times10^{-5}$ torr by a turbomolecular pump at the Mirror Optics Unit (MOU) and a similar pump on a special section of waveguide near the tokamak, where the waveguide has been slotted to allow pumping between the corrugations. This waveguide pumping section is placed as close to the DIII–D vacuum vessel as practical so that any impurities evolved from the waveguide upstream of the tokamak can be pumped out before they reach the plasma and possibly contaminate it. However in the case of a catastrophic vacuum failure, there is a fast shutter located just upstream of the pumping section, this shutter can close faster than the pressure wave can travel down the waveguide and in conjunction with the pumping section, maintains the vacuum pressure at the tokamak entrance waveguide long enough for the torus isolation valve to close ≈ 0.8–1 s.

Polarization control is achieved by a set of grooved polarizing mirrors mounted in two of the mitre bends. By appropriate rotation of these two mirrors, any elliptical polarization desired can be obtained. Inside the tokamak are two mirrors, a focusing mirror and a flat turning mirror, permanently angled at 19° off normal to provide the appropriate current drive injection. The tilting mirror rotates vertically so the injected beam can be skewed poloidally from slightly below the midplane of the plasma, to the outermost top edge of the plasma. To aid in gyrotron optimization a dummy load is connected to the system via a waveguide switch located near the gyrotron.

INITIAL OPERATION INTO DIII–D

An important issue for the usefulness of the ECH system is the validation of the spot size that interacts with the plasma. The launcher was designed to inject the rf beam 19° off-normal to drive current, and analysis of the launcher optics predicts that 98% of the rf power will be in an area with a diameter of 19.7 cm at the plasma center. The Full Width Half Maximum (FWHM) value for a Gaussian beam with a 19.7 cm 98% power spot size is 8.3 cm. The actual power deposition profile was measured from IR images of the microwave beam from short pulses through the system without a vacuum impinging on a paper target placed inside the DIII–D vacuum vessel at the plasma center location. These measurements for

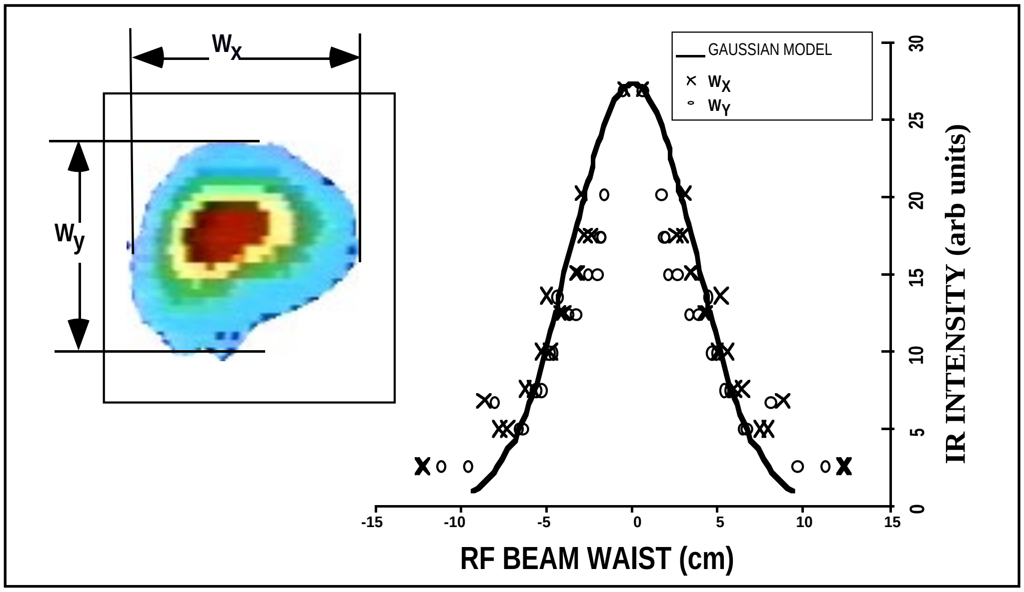

FIGURE 1. Power deposition profile measured from IR camera images if the rf beam striking a paper target placed at the center of the DIII–D vacuum vessel. The Gaussian profile developed from the launcher optics is also shown.

the Gycom gyrotron are summarized in Fig. 1. The power deposition profile is seen to match the expected Gaussian profile except for a low level wing, which may indicate the presence of some higher order modes. Initial operation and deposition profile measurement of the first CPI gyrotron has been completed and the results are similar to those with the Gycom gyrotron

One of the other useful applications of ECH is the determination of the localized thermal transport coefficient. To perform this measurement the rf power is modulated at a relatively high repetition rate. This is achieved by modulating the gyrotron voltage by only 16% for the GYCOM gyrotron and by turning on and off the mod-anode on the CPI gyrotron.

Injection of approximately 500 kW into low density plasmas has resulted in central electron temperatures of 10 keV as shown in Fig 2. The electron temperature profile is determined from a Michelson interferometer, a heterodyne radiometer, and Thomson scattering.

CONCLUSION

The first of three MW ECH systems is operating routinely at DIII–D with generated power at 110 GHz of approximately 900 kW, pulse lengths up to 500 ms and good power accountability. Initial rf power injection into a DIII–D plasmas has been performed for 500 ms both unmodulated and modulated. The MHD measurements of the plasma energy increase indicates that about 550 kW

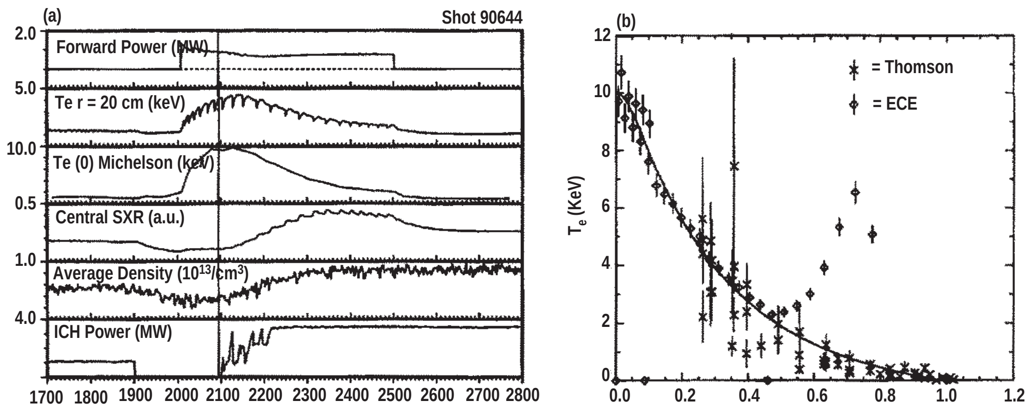

FIGURE 2. Time dependence of the forward rf power and several diagnostic traces during ECH heated plasmas: (a) the electron temperature profile (b) from ECE and Thomson scattering is shown by the vertical line on the time plots.

was absorbed for 800 kW generated. Initial operation and deposition profile mapping of the first CPI gyrotron has been completed at short pulses.

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