GA–A23208

POLARIZATION MEASUREMENTS DURING ELECTRON CYCLOTRON HEATING EXPERIMENTS IN THE DIII–D TOKAMAK

by
C.C. PETTY, T.C. LUCE, M.E. AUSTIN, H. IKEZI,
J. LOHR, AND R. PRATER

JULY 1999

DISCLAIMER

GA–A23208

POLARIZATION MEASUREMENTS DURING ELECTRON CYCLOTRON HEATING EXPERIMENTS IN THE DIII–D TOKAMAK

by
C.C. PETTY, T.C. LUCE, M.E. AUSTIN,* H. IKEZI,
J. LOHR, AND R. PRATER

This is a preprint of a paper presented at the Fourth International Workshop on Strong Microwaves in Plasmas, August 29, 1999 in Nizhny Novgorod, Russia, and to be published in *The Proceedings.*

*University of Texas at Austin, Austin, Texas.

Work supported by
the U.S. Department of Energy
under Contract No. DE-AC03-99ER54463,
and Grant No. DE-FG03-97ER54415

GA PROJECT 30033
JULY 1999

POLARIZATION MEASUREMENTS DURING ELECTRON CYCLOTRON HEATING EXPERIMENTS ON THE DIII–D TOKAMAK

C.C. Petty, T.C. Luce, M.E. Austin, H. Ikezi, J. Lohr, and R. Prater*

General Atomics, P.O. Box 85608, San Diego, California, 92186-5608, USA

*University of Texas at Austin, Austin, Texas.

The polarization of the launched electron cyclotron wave has been optimized for coupling to the X–mode by adjusting the inclination of grooved mirrors located in two consecutive mitre bends of the waveguide. The unwanted O–mode component of the launched beam can be positively identified by the difference in the power deposition profiles between X–mode and O–mode. The optimal polarization for X–mode launch is in good agreement with theoretical expectations.

Electron cyclotron heating (ECH) and current drive (ECCD) experiments on the DIII–D tokamak need narrow beams in nearly pure X–mode to achieve the highly localized deposition and current drive required for advanced tokamak scenarios. The electron cyclotron waves are launched from the low-field-side of the tokamak using two 110 GHz gyrotrons (“Katya” and “Dorothy”), corresponding to the second harmonic of the electron cyclotron frequency. The two gyrotrons are capable of 1.7 MW of combined power for 1 s pulses. For current drive experiments, a toroidal launch angle of 19° is used, while perpendicular launch is also possible for pure heating applications using a different mirror geometry. The ECCD launcher is steerable in poloidal angle which allows the deposition location to be varied from the plasma center to the edge.

The polarization of the launched wave is controlled by adjusting the inclination of grooved mirrors located in two consecutive mitre bends of the evacuated waveguide.[1] This type of polarizer produces a polarization dependent phase delay since the wave is reflected from the top of the grooves when the electric field is aligned to the groove, whereas the wave is reflected from the bottom of the grooves when the electric field is perpendicular to the groove. Nearly any mixture of X–mode and O–mode power is possible using these polarizers. For perpendicular launch, the desired polarization for X–mode is linearly polarized (ellipticity = 0) with an inclination of 90° relative to the magnetic field at the plasma edge.

The power deposition profile is determined experimentally by modulating the ECH power at 100 Hz and measuring the electron temperature (T_e) response using a 32-channel heterodyne radiometer.[2] In the limit of infinite modulation frequency (ω), the temperature response $\left(\tilde{T}_e\right)$ is everywhere proportional to the ECH source term with a 90° phase lag from the injected power. For square wave modulation, the power deposition profile can be found from[3]

$$P_{abs} = \frac{2\omega}{\pi}\,\frac{3}{2} n_e \tilde{T}_e \quad , \tag{1}$$

where n_e is the electron density. However, this equation places only an upper bound on the deposition profile width for the relatively low modulation frequency of 100 Hz used in these experiments.

Experimental Results

Recent experiments on DIII–D have verified the correct operation of the polarizers by scanning the mixture of X–mode and O–mode power by changing the inclination and ellipticity of the launched beam. Perpendicular launch of the ECH is used in this experiment since this allows the regions of deposition for X–mode power and O–mode power to be easily separated, as described below and shown in Fig. 1. The X–mode component is strongly absorbed off-axis at the location of the second harmonic ECH resonance, whereas the O–mode component is weakly absorbed owing to the low electron temperature off-axis. The remaining O–mode component of the wave reflects off of the graphite inner wall and makes a second pass through the plasma, this time passing close to the plasma center where the O–mode power is more strongly absorbed due to the higher electron temperature.

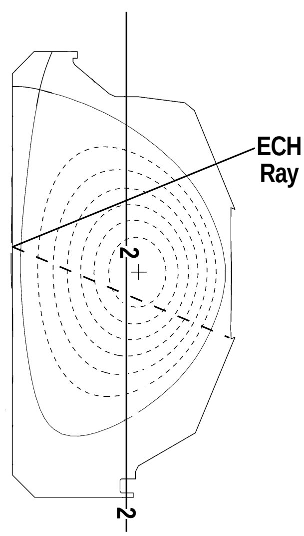

Fig. 1. Vacuum ray paths for perpendicular launch of electron cyclotron waves for these experiments.

Measurements of the power deposition profile can clearly resolve the separate X–mode and O–mode peaks, as shown in Fig. 2. In the case of Fig. 2(a) for the Katya gyrotron, the mixture of X–mode power and O–mode power is varied by changing the inclination of the linear polarized launched beam, whereas in the case of Fig. 2(b) for the Dorothy gyrotron, the ellipticity of the launched beam is changed as well. Figure 2 shows that the X–mode component is absorbed near $\rho \approx 0.55$, where ρ is the normalized toroidal flux coordinate. After reflecting off the inner wall, the O–mode component is seen to damp near $\rho \approx 0.15$. The relative size of the X–mode and O–mode peaks are in good agreement with the expected X–mode and O–mode powers based on the polarizer settings.

Scans of the wave inclination show that the launched X–mode power is optimized for an inclination near 90°, which agrees with theoretical expectations for perpendicular injection. Figure 3(a) shows the measured power deposition profiles for Katya during an inclination scan about the optimal X–mode launch point. The unwanted O–mode component is seen to increase as the inclination moves away from 90° in either direction. Conversely, the magnitude of the X–mode component increases as the inclination moves closer to 90°. A similar result is obtained for Dorothy, as shown in Fig. 3(b).

Scans of the wave ellipticity show that the unwanted O–mode power is minimized for an ellipticity near 0, in agreement with theory for perpendicular launch. This is shown in Fig. 4(a) for Katya and Fig. 4(b) for Dorothy. Since the O–mode component in Fig. 4(a) never completely

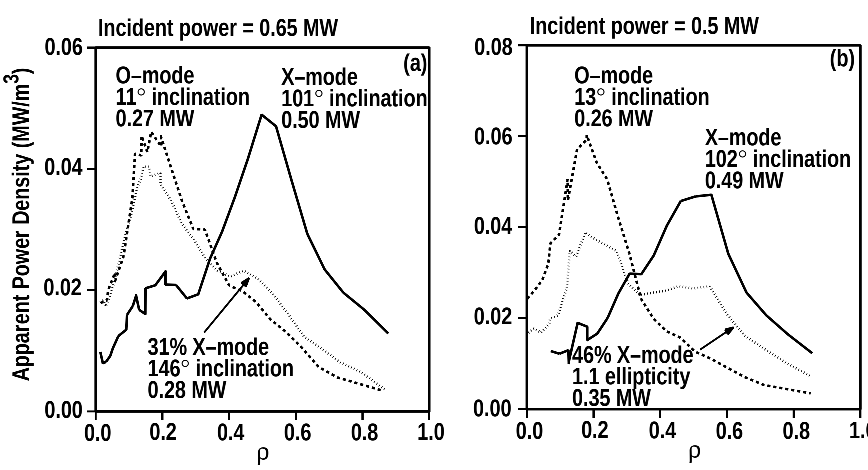

Fig. 2. Power deposition profiles for X–mode and O–mode launch for (a) Katya, and (b) Dorothy. The integrated absorbed powers are also indicated.

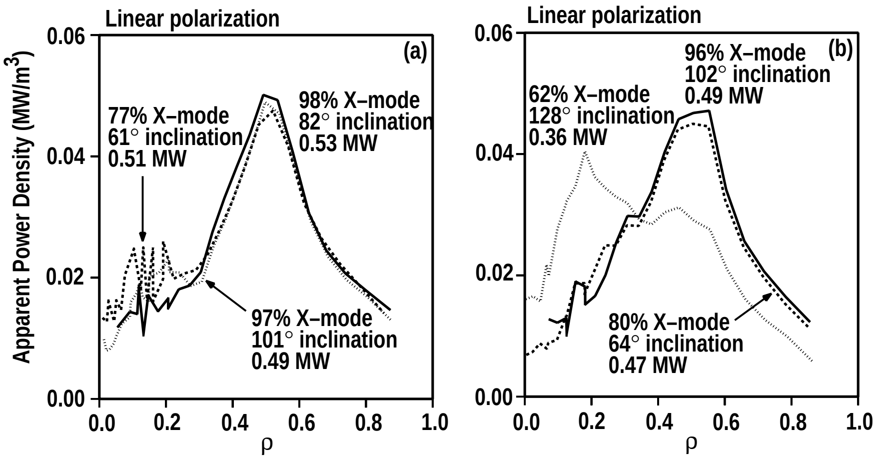

Fig. 3. Power deposition profiles for an inclination scan about the optimal X–mode point for (a) Katya, and (b) Dorothy. The integrated absorbed powers are also indicated.

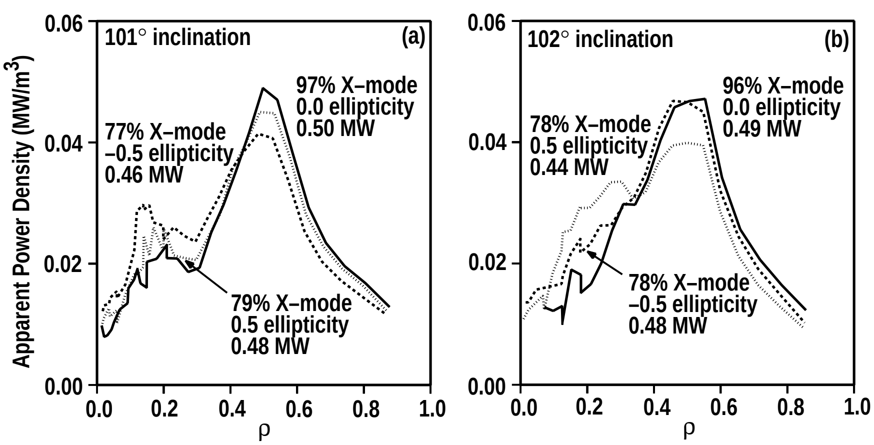

Fig. 4. Power deposition profiles for an ellipticity scan about the optimal X–mode point for (a) Katya, and (b) Dorothy. The integrated absorbed powers are also indicated.

disappears, even for an ellipticity of 0, this would indicate that the inclination has not been set to the ideal value for X–mode launch. There is also a puzzling asymmetry in the magnitude of the measured O–mode power for ellipticities of ±0.5. In Fig. 4(a), the O–mode peak for Katya is lower for an ellipticity of 0.5 compared to –0.5, while in Fig. 4(b), the

O–mode peak for Dorothy is higher for an ellipticity of 0.5 compared to –0.5. Although this asymmetry is not understood presently, it may be related to the slightly different toroidal angular components for the two ECH systems since the launchers actually inject ±2° from perpendicular.

Conclusions

Experiments on DIII–D have shown that the polarization of the launched electron cyclotron waves can be controlled by adjusting the inclination of grooved mirrors located in two consecutive mitre bends of the waveguide. The X–mode and O–mode components of the launched beam can be identified by their different deposition profiles, determined by modulating the ECH power and measuring the electron temperature response. For perpendicular injection of the waves, the experimentally determined polarization for optimal X–mode launch is in agreement with theory. This gives confidence that the required polarization for X–mode launch in the more difficult situation of current drive injection can be correctly obtained.

Acknowledgment

This is a report of work supported by the U.S. Department of Energy under Contract No. DE-AC03-99ER54463 and Grant No. DE-FG03-97ER54415.

References

1. Doane, J.L., Int. J. Infrared Millimeter Waves 13, 1727 (1992).
2. Wang, Z., et al., Proc. of the 9th Int. Workshop on Electron Cyclotron Emission and Electron Cyclotron Heating, Borrego Springs, California, (World Scientific, 1995) p. 427.
3. Murakami, M., et al., Proc. of the 10th Int. Conf. on Radiofrequency Power in Plasmas, Boston, Massachusetts (American Institute of Physics, 1993) p. 48.