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Determination of ECCD Current Profiles in DIII–D Discharges Using a Local Representation Method

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Abstract: A local representation is used to determine localized features in the current profiles due to ECCD in the DIII–D tokamak discharges from equilibrium reconstruction based on spectroscopic and external magnetic measurements. Initial results indicate that reconstruction using a local basis function can resolve very peaked ECCD profiles. The reconstructed narrow ECCD profiles are consistent with the quasi-linear Fokker-Planck results from the CQL3D code.

A key element of the DIII–D research program is the use of the electron cyclotron current drive (ECCD) to control and sustain the current profile for advanced tokamak study. An important issue is the determination of the ECCD profiles. This is both for controlling as well as for testing of theoretical ECCD models. A convenient method for determination of ECCD profile is the flux evolution approach [1] based on a time series of magnetohydrodynamic (MHD) equilibrium states reconstructed from motional Stark effect (MSE) spectroscopic measurements of pitch angles of internal magnetic field lines and external magnetic measurements using the EFIT equilibrium reconstruction code [2]. Previous analysis results of DIII–D discharges with off-axis ECCD obtained using this approach show that the widths of the reconstructed ECCD profiles are generally broader than those predicted theoretically [3]. The MHD equilibria used in the analysis are reconstructed using a smooth polynomial representation. There are indications from the ECCD transport simulations that the narrower predicted ECCD profiles are consistent with the MSE data and that the discrepancy may be due to the finite spatial resolution and the smooth basis representation used in the EFIT equilibrium reconstruction [4]. To resolve this discrepancy, a representation which allows localized features with strong gradients in the current profile has been implemented in the EFIT code.

The contribution to the ECCD current profile from the poloidal current function term FF'_{ψ} computed from the ray tracing package ONETWO/TORAY-GA [5] exhibits a large localized component and can only be fully described using a polynomial basis function plus a local representation such as a cosine square function. This is illustrated in Fig. 1, where the FF'_{ψ} term computed from ONETWO/TORAY-GA is compared against a representation using a smooth polynomial function only and one using a polynomial function plus a local cosine square function. Motivated by these results, a new local representation method has been developed where the toroidal current density

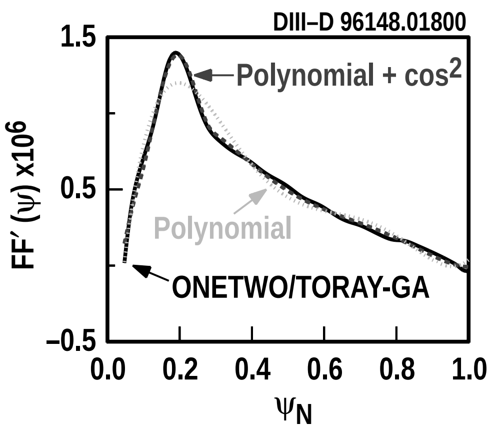

Figure 1. The ECCD profile given by the poloidal current term FF'(ψ) (solid curve) of the toroidal current density computed using the ONETWO/TORAY-GA package can be conveniently described by a polynomial function plus a local cosine square term (dashed curve) but not by the polynomial alone.

J_ϕ is conveniently represented as a smooth background component plus a local component due to ECCD:

$$J_\phi(R,Z) = J_{\phi 0}(R,Z) + J_{local}(R,Z) \quad , \tag{1}$$

where $J_{local} = FF'_{local}(\psi)/R$ and

$$FF'_{local}(\psi) = C\cos^2 kx,\ \text{when } |x| \le \Delta 0,\ \text{otherwise} \quad . \tag{2}$$

Here C is the local current density amplitude, $k=\pi/(2\Delta)$, $x=\psi_n-\psi_0$, ψ is the poloidal flux, $\psi_n = (\psi-\psi_m)/(\psi_b-\psi_m)$ is the normalized poloidal flux, ψ_m and ψ_b are the poloidal flux at the magnetic axis and at the plasma boundary, ψ_0 is the normalized poloidal flux at the local current density peak location, Δ is the half width of the local current density channel, and $J_{\phi 0}$ is the smooth back ground current density. The poloidal current function F is related to the toroidal current density J_ϕ through the Grad-Shafranov equilibrium equation

$$R^2\nabla \bullet \frac{\nabla\psi}{R^2} = -\mu_0 R J_\phi, \quad J_\phi = RP'(\psi) + \frac{\mu_0 FF'(\psi)}{4\pi^2 R} \tag{3}$$

where P is the plasma pressure.

The amplitude C is determined similarly as other current profile parameters from MSE and external magnetic measurements by directly inverting the response matrix A at each equilibrium iteration using the singular value decomposition method [2]

$$\alpha = A^{-1}M \quad , \tag{4}$$

where α is the current profile parameter vector and M is the measurement vector. The local current density peak location and the current channel half width ψ_0 and Δ are determined from the measurements in a separate external optimization loop.

Initial reconstruction results show that the new local cosine square representation can resolve the very peaked ECCD current profiles in the DIII–D discharges and the reconstructed ECCD current profiles agree well with the theoretical predictions from the quasi-linear Fokker-Planck calculations using the CQL3D code [6]. This is illustrated in Fig. 2, where the reconstructed ECCD profiles using a smooth polynomial basis function and a polynomial plus a local cosine square representation are compared against the theoretical predictions from CQL3D. To improve the spatial resolution, the EFIT equilibrium reconstructions are computed using 129 × 129 radial and vertical grid points. For this particular reconstruction, $\psi_0 = 0.055$ and $\Delta = 0.04$.

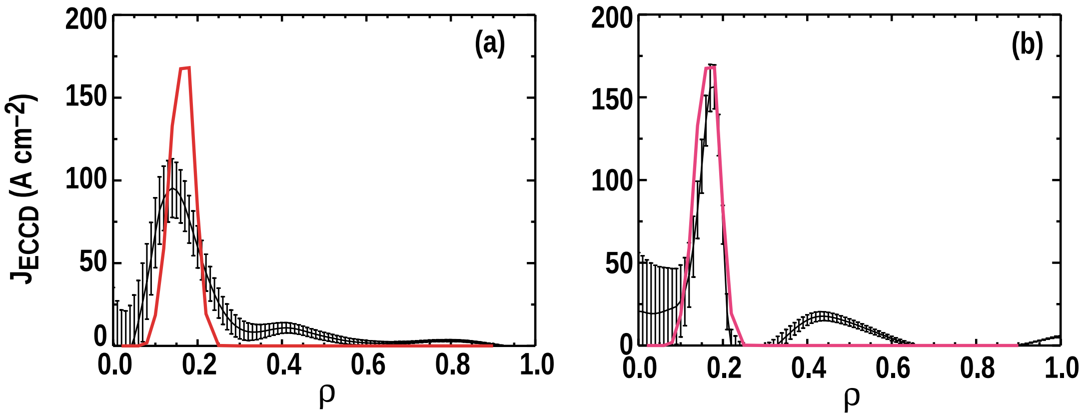

Figure 2. Comparison of reconstructed ECCD profiles (hatched curves) for DIII–D discharge 96163 using (a) a polynomial basis function and (b) a polynomial plus a local cosine square representation against the quasi-linear Fokker-Planck results from the CQL3D code (solid curves).

Employing a local component in the current profile representation is crucial in order to match the central MSE measurements in the DIII–D ECCD discharges, particularly when the ECCD is near the magnetic axis and the ECCD current density is large. This is illustrated in Fig. 3, where the flux surface averaged toroidal current density <J_ϕ> and the figure of merit describing fitting to the MSE signals χ^2_{MSE}, with and without a local cosine square in the current profile representation, are compared. This difference in χ^2_{MSE} arises mostly from the central MSE channels around the location of the ECCD

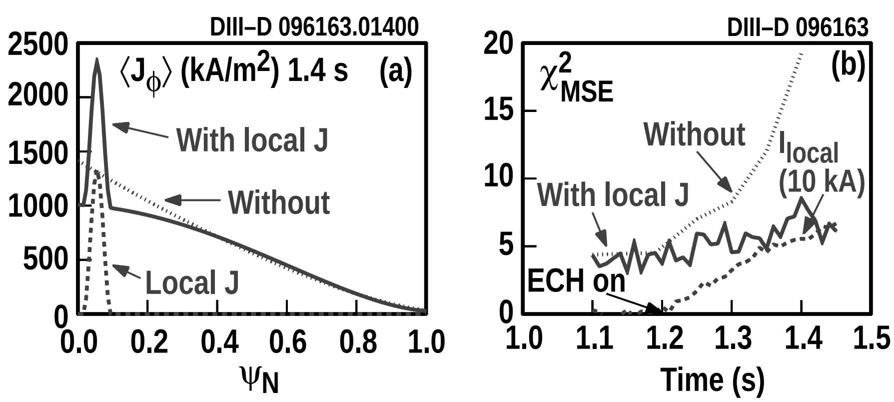

Figure 3. (a) Comparison of reconstructed current profiles <J_ϕ> with (solid curve) and without a local component (dotted curve) for DIII–D discharge 96163 at 1400 ms. Also shown is the local component (dashed curve). (b) χ^2_{MSE} with (solid curve) and without a local component (dotted curve) at various times before and after ECH is turned on. Also shown is the total local current I_{local} (dashed curve).

profile. The external magnetic fitting figures of merit χ^2_{MSE} remain similar with and without the local cosine square component. This is to be expected, since external magnetic measurements only yield global current profile information but not the local variation of the current density profile. Also shown in Fig. 3(b) is the total ECCD current at various times before and after the ECH power is turned on.

Local changes in the current profile due to ECCD can be detected using this local representation approach. This is illustrated in Fig. 4, where the local changes in the ECCD profiles $\delta J_\phi(\delta t) = J_\phi(\delta t) – J_\phi(0)$ at various times before and after the ECH power is turned on, reconstructed with and without the local cosine square basis function in the current profile representation, are compared.

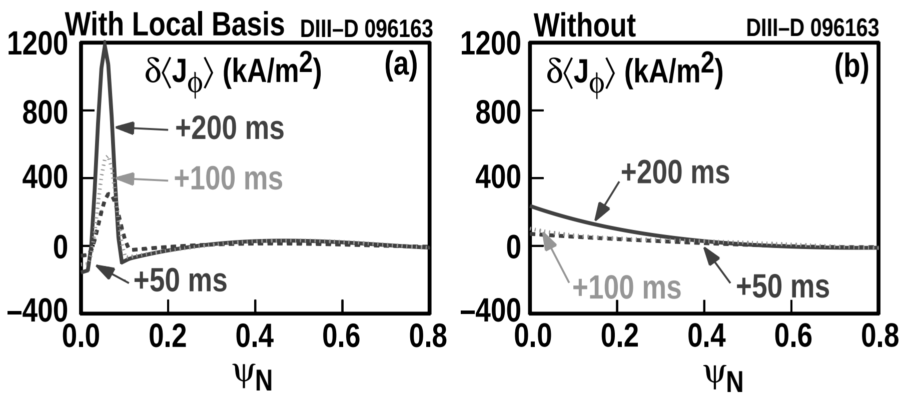

Figure 4. Comparison of the local changes in the reconstructed current profiles $\delta\langle J_\phi\rangle$ for DIII–D discharge 96163 at 50 ms (dashed curves), 100 ms (dotted curves), and 200 ms (solid curves) after ECH is turned on (a) with a local cosine square basis function in the current profile representation and (b) without.

In summary, a local represention method has been developed and successfully applied for determination of highly localized ECCD current profiles in DIII–D. The reconstructed narrow ECCD profiles are consistent with the quasi-linear Fokker-Planck results from CQL3D [6]. Accurate MSE measurements around the ECCD location are crucial for the determination of the ECCD profiles.

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