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Poloidal Field Measurements in the ST Tokamak by Harmonic Generation at the Upper Hybrid Layer

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The initial experiments [1] on local generation of the harmonic wave in the ST tokamak with an electromagnetic wave propagating along the major radius R revealed that the harmonic power characteristic matched the predictions of the theory for generation at the upper hybrid layer [2]. However, the observed minimum of the harmonic power component ratio $P_{ord}/P_{ext} \sim 10^{-2}$ was too large to permit the harmonic polarization measurements which are required to specify the poloidal magnetic field $B_y(r)$. Experimental improvements have resulted in a substantial reduction in the minimum of P_{ord}/P_{ext} (to $\sim 10^{-3}$) so that we are now able to resolve changes in polarization which although the measurements are preliminary, are commensurate with the expected poloidal effect at the upper hybrid layer.

The method used here is discussed in detail elsewhere [3]. Briefly, a locally generated extraordinary wave with frequency Ω, propagating in a plasma with $\omega_p << \omega_c \lesssim \Omega/2$, maintains its initial polarization. Therefore, remote polarization measurements yield the direction of the confining magnetic field at the point of generation.

In Ref.3, the case of a linearly polarized harmonic is discussed. For elliptical polarization, the direction of the local magnetic field is obtained from the rotation of the ellipse. The measurement of the rotation in this case requires the simultaneous detection of the amplitudes and phases of the harmonic electric field components. Let θ be the angle of the magnetic field with respect to the z axis (defined here as the horizontal polarimeter axis) and $E_\perp$, $E_\parallel$, and ψ be the wave components and their relative phase in the local magnetic field frame. Then correspondingly in the laboratory (polarimeter) frame

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$$\frac{|E_z|^2}{|E_y|^2} = \frac{|E_{\parallel}|^2}{|E_{\perp}|^2}\left(1 - 2\frac{|E_{\perp}|}{|E_{\parallel}|}\theta\cos\psi + \frac{|E_{\perp}|^2}{|E_{\parallel}|^2}\theta^2\right), \quad (1)$$

and

$$\tan\chi = (|E_{\perp}|\,\theta/|E_{\parallel}|)\sin\psi + \text{constant}, \quad (2)$$

where θ is assumed small and χ is the relative phase between E_y and E_z. In the absence of plasma current, the polarimeter is rotated to give $\theta = 0$ and the polarimeter measurements of $|E_z|^2/|E_y|^2$ and χ give the ellipticity $\varepsilon = |E_{\parallel}|/|E_{\perp}|$ and the constant of Eq.(2).

Figure 1 gives the present experimental arrangement. A carcinotron (f = 33.6 GHz) modulated at 50 kHz and delivering up to 15 watts of incident power is used in place of the lower power klystron of the initial experiments [1]. Improved horn allignment and the addition of a microwave absorber provide the reduced ellipticity already mentioned. The polarimeter is now rotatable to permit θ scans and finally, a phase comparator has been added to give the phase χ simultaneously with the amplitude measurements.

In Fig.2, $|E_z|^2/|E_y|^2$ is plotted versus θ at two times for a helium discharge with the magnetic field on the vessel axis set at $B_z(x = 15\text{cm}) = 14.1$ kG. The experimental points are found to fit parabolic curves as predicted by Eq.(1) with $\psi \approx \pi/2$. The axes of the polarimeter and of the ellipse coincide at the minimum of $|E_z|^2/|E_y|^2$. Rotation of the magnetic field due to plasma current is measured by the shift of the minimum between the zero current (t = 0) and the maximum current (t = 6ms) cases. This shift of $\sim 1.5^0$ is in good agreement with the value expected at the upper hybrid layer, $r \approx 20$ cm, which for the selected B_z is outside the limiter so that $\theta \sim I_z/5rB_z \sim 1.2^0$.

Figure 3 presents the measured values of χ versus θ for the discharge conditions of Fig.2. Within the experimental errors, $\tan\chi \sim \chi$ is proportional to θ. The separation at $\theta \sim 0$ between the two curves yields the angle of rotation of the magnetic field whereas the slopes give the ellipticity at the respective times; $\varepsilon \sim 6.4 \times 10^{-2}$, 7.5×10^{-2} in reasonable agreement with the values obtained from direct calibration of the detected amplitudes of $\varepsilon \sim 4 \times 10^{-2}$, 4.6×10^{-2} for $t = 0$, 6 msec.

By varying the level of the toroidal field for a fixed polarimeter position and constant incident frequency, a preliminary measurement of the radial profile of $\theta = B_y/B_z$ may now be obtained. Combining these measurements of θ with the location of the upper hybrid layer deduced from Thomson scattering measurements of the electron density profile for similar discharge conditions gives the poloidal field profile plotted in Fig.4. The expected peak in B_y (in Fig.4, $\theta = B_y/14.1 \times 10^3$ G) is clearly observed as is the 1/r variation outside the current channel.

The location of the peak in Fig.4 is indicative of a rather flat current distribution. However, remaining uncertainties in the measurements of θ plus the need for more exact density profile measurements taken simultaneously with the θ data preclude a definite determination of the current distribution at this time.

The results reported here demonstrate that the harmonic polarization is in fact sensitive to the poloidal field at the upper hybrid layer. Future experiments are planned at twice the present incident frequency for which we expect to reduce further the harmonic ellipticity and obtain more reliable density profiles so that a quantitative measurement of the poloidal field profile, or equivalently the current density profile, may be obtained.

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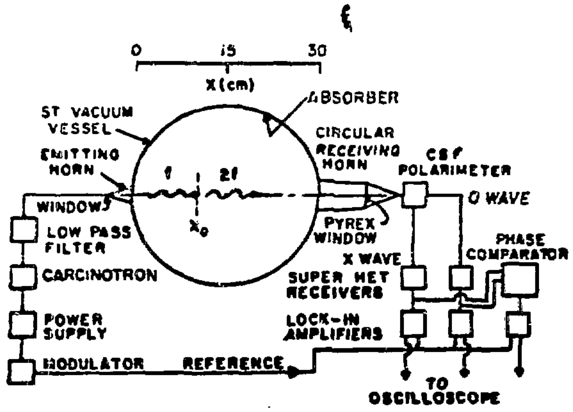

Fig. 1

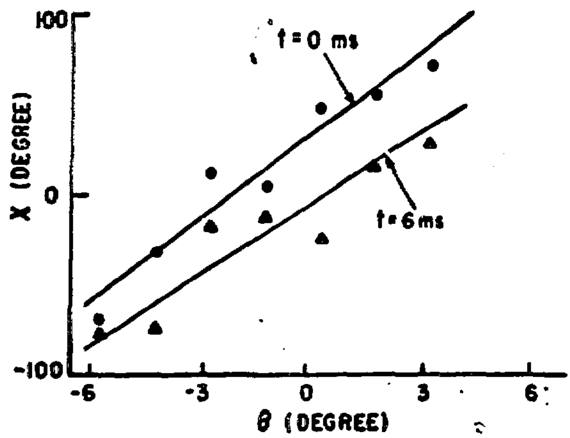

Fig. 3

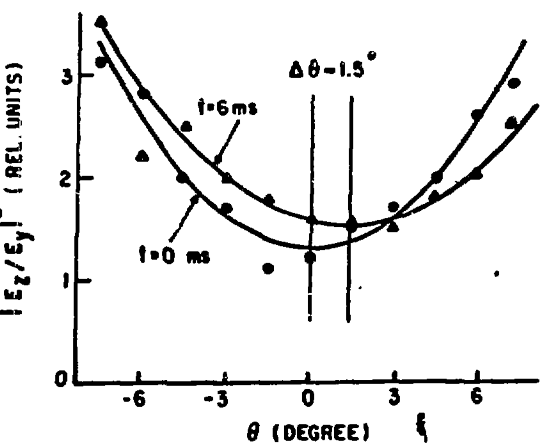

Fig. 2. $|E_z/E_y|^2$ versus θ for a helium discharge (B_z = 14.1 kG, a = 10.6 cm). For t = 0, I_z = 0 and for t = 6 msec, I_z = 26 kA and $n_e(r = 0) = 7 \times 10^{12}$ cm^{-3}.

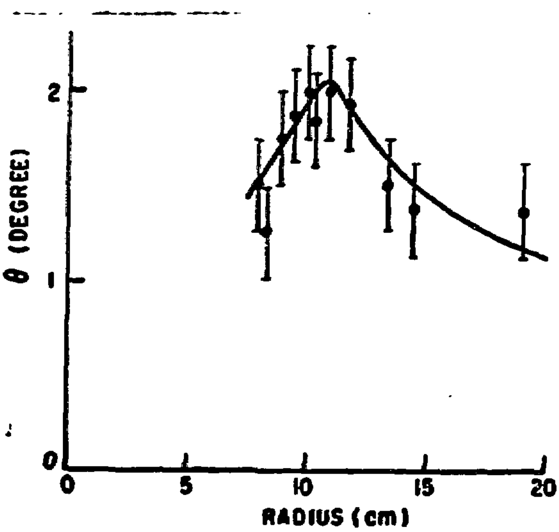

Fig. 4

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