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PLASMA MASS DENSITY, SPECIES MIX AND FLUCTUATION DIAGNOSTICS USING FAST ALFVÉN WAVE

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GENERAL ATOMICS

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PLASMA MASS DENSITY, SPECIES MIX AND FLUCTUATION DIAGNOSTICS USING FAST ALFVÉN WAVE

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ABSTRACT

We propose to employ a fast Alfvén wave interferometer and reflectometer as a tokamak diagnostic to measure the plasma mass density, D–T species mix profile, and density fluctuations. Utilize the property that the phase velocity of the fast wave propagating across the magnetic field is the Alfvén speed with thermal correction, this fast wave interferometer on the DIII–D tokamak was successfully used to obtain the line integrated density. Since the position of the ion-ion hybrid cut-off in tokamaks is uniquely determined by the species mix ratio and the wave frequency, the reflectometer arrangement finds the species mix profile. The inversion method of reflectometry is discussed. The multiple chord interferometer also measures the mass density fluctuation profile.

I. MASS DENSITY

The phase velocity of the fast wave propagating across the magnetic field equals the Alfvén speed, $v_A = B/(4\pi\rho)^{1/2}$, with the plasma pressure correction

$$\omega/k_{\perp} = v_A (1 + \beta)^{1/2} \qquad (1)$$

if the frequency is higher than a few times the ion cyclotron frequencies, $\omega/\Omega_i \gtrsim 3$. The measurement of wave phase (wavelength) by interferometry gives the mass density, ρ. The appropriate frequency for a D-T plasma of density = 10^{14}/cc with B = 4.5 T is typically 200 MHz which gives the wavelength in the plasma of 3 cm.

The wave sensor can be a single turn $\dot{B}$ loop of 1–2 cm in diameter. A loop antenna can also be used for the wave launcher. The antenna and the sensor loops can be placed behind the first wall with the signals propagating through the gaps in the wall. The required power level is a few watts. The density profile data may be obtained by employing an array of sensor loops.

The preliminary tests of the fast wave interferometer have been carried out on DIII–D and indicate good agreement with a CO_2 laser interferometer.[1] An example of the results is shown in Fig. 1. The difference of the results from two interferometers at higher density, where the neutral beam is injected, is partially due to the fact that the cord locations are different. The parameters employed are: $\omega/2\pi =$ 60 MHz, B = 1 T and 2 T, transmitter power = 10 W. The $\dot{B}$ loops used survive up to 500°C.

The frequency can be swept in a wide range very easily at the fast wave frequency range. The frequency dependence of the phase shift determines the density instantaneously. This operation of interferometer avoids the fringe counting errors which occur in the laser interferometers.

This is a simple diagnostic which does not have the vibration elimination difficulties arising in CO_2 laser system. Since the frequency is in the VHF band and the sensors and antenna are only $\dot{B}$ loops, this is a low cost diagnostic which can give real time response.

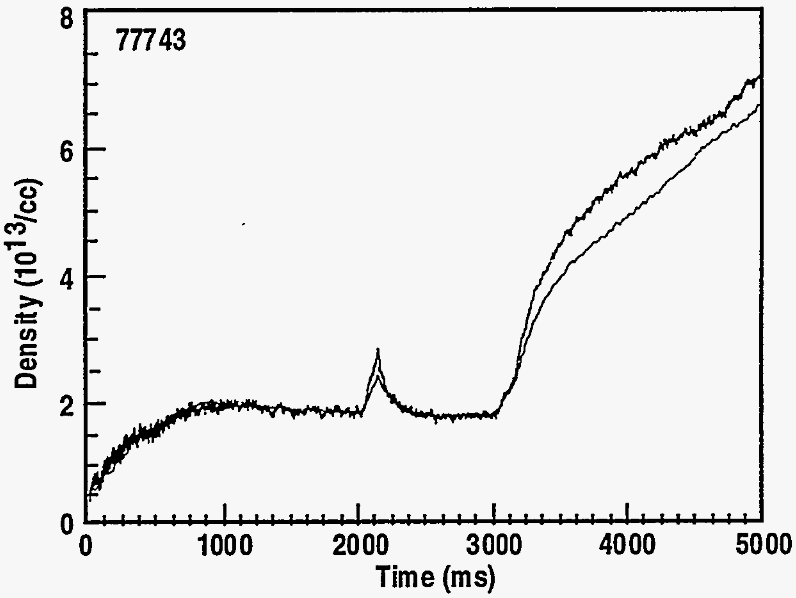

Fig. 1. Densities measured by both the CO_2 interferometer (noisier curve) and by the Alfvèn speed (quieter curve).

II. D-T CONCENTRATION RATIO

The fast wave has ion-ion hybrid resonance(s) if the plasma consists of two or more ion species. The resonance and cut-off frequencies are uniquely determined by the species mix ratio.

The index of refraction perpendicular to B is given by $N_\perp^2 = RL/S$ in Stix's notation.[2] The resonance and cut-off frequencies, determined by $S = 0$ and $R = L = 0$, are

$$\omega_{res} = \left[\frac{3-f}{3+(3/2)f}\right]^{1/2} \Omega_D$$
$$\omega_{cut} = \left(1 - \frac{1}{3} f\right) \Omega_D \qquad (2)$$

in a D-T plasma with the deuterium concentration fraction, f. Here, Ω_D is the ion cyclotron frequency of deuterium. In a non-uniform magnetic field, $B \propto 1/R$, in a tokamak, ω_{res} and ω_{cut} depend on R schematically as shown in Fig. 2. For a given frequency, ω, the position of the resonance and cut-off, R_{res} and R_{cut}, are uniquely determined by f.

The index of refraction profile is like that shown in Fig. 3. The fast wave launched inward from the outer boundary is reflected at $R = R_{cut}$ and goes back to the outer boundary. A receiver $\dot{B}$ loop

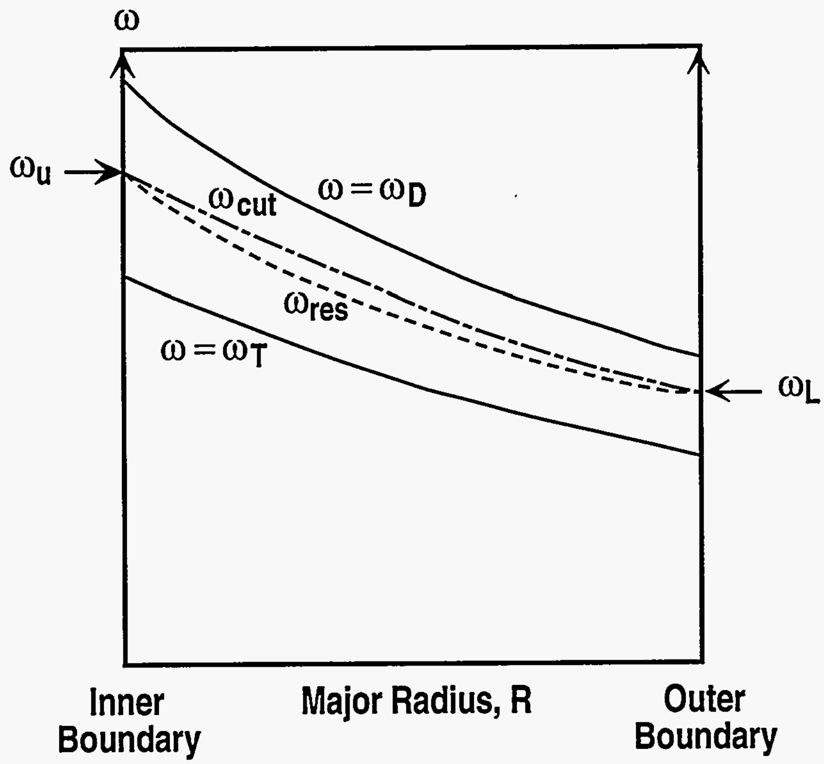

Fig. 2. The ion cyclotron frequencies of deuterium and tritium, ω_D and ω_T, and resonance and cut-off frequencies as a function of tokamak major radius.

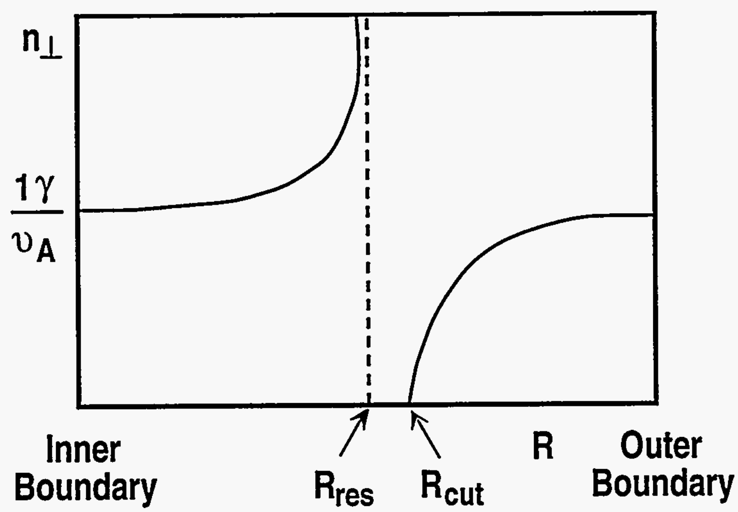

Fig. 3. The Alfvèn index of refraction, $n_\perp \equiv \upsilon_A k_\perp/\omega$, as a function of major radius.

outside the outer boundary picks up the reflected wave. The measurement of this round trip phase shift (reflectometry) finds R_{cut} with the aid of the mass density information obtained by the previously described diagnostic.

By sweeping the frequency, the profile of f may be obtained. Figure 2 also indicates that the wave propagates across the plasma at the frequencies $\omega < \omega_L$ and $\omega > \omega_u$. The lower end of the absorption band ω_L gives f at the outer boundary and the upper end frequency ω_u determines f at the inner plasma boundary.

We have made the computer code to invert the phase vs. frequency data to the species mix as a function of radius. We have adopted a simple numerical method given by Doyle, et al.[3] The computation time is short enough to process the data between the usual tokamak shots.

The proof-of-principle experiments of the reflectometer will be carried out on the DIII–D tokamak in the near future.

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[3]E. J. Doyle, T. H. Lehecka, N. C. Luhmann, Jr., W. A. Peebles, and the DIII–D Group, Rev. Sci. Instrum. **61**, 2896 (1990).