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EXTENSION OF CONFINEMENT AND NEUTRAL INJECTION EXPERIMENTS IN ORMAK TO HIGHER PARAMETERS*

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Abstract: The ORMAK operating regime has been extended to higher toroidal fields (25 kG), higher discharge currents (200 kA), and higher injection power (500 kW), resulting in improved plasma parameters. Specifically, ion heating increases approximately linearly with coinjection power. For counterinjection, ion heating efficiency increases while fast ion loss and deleterious plasma perturbations decrease with increasing discharge current.

Machine Operating Improvements: Previous studies of confinement[1] and neutral beam injection[2] in ORMAK were conducted at toroidal fields $B_T \leqslant$ 18 kG, discharge currents $I_T \leqslant$ 130 kA, and injection power $P_{inj} \leqslant$ 90 kW per injection direction. Since the Tokyo IAEA conference, the experimental emphasis has been on confinement and neutral beam injection studies at improved machine parameters (B_T up to 25 kG, I_T up to 200 kA, P_{inj} up to 500 kW), with feedback control of the vertical field and with oxygen rather than hydrogen discharge cleaning.

Oxygen versus Hydrogen Discharge Cleaning: Replacing hydrogen with oxygen for discharge cleaning of the vacuum liner has improved the general plasma characteristics but narrowed the density range for stable operation. Figure 1(a) shows the behavior $\bar{n}_e(t)$, I(t), and V(t) for similar discharges preceded by oxygen discharge cleaning (solid curves) and by hydrogen discharge cleaning (dashed curves). The main difference occurs in the mean density history which peaks early and then decays with hydrogen discharge cleaning, but rises more slowly initially and then remains constant for most of the shot with oxygen discharge cleaning. Figure 1(b) shows the relative amounts of H_β line intensity normalized to electron density for plasmas

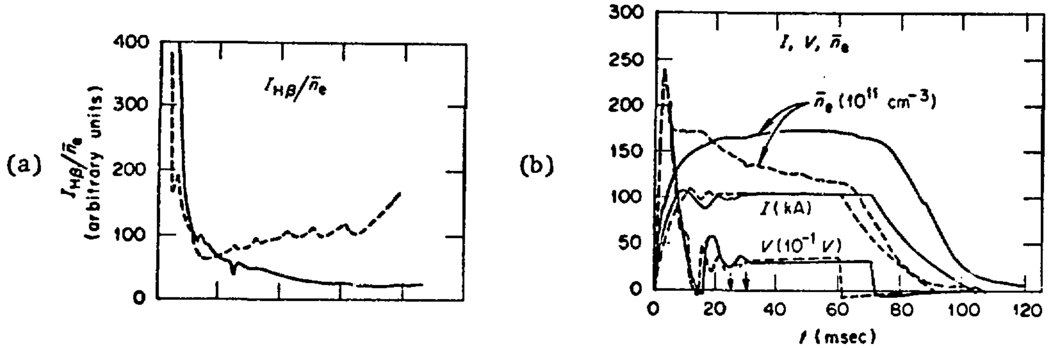

Fig. 1. Oxygen versus Hydrogen Discharge Cleaning.

preceded by oxygen (solid curve) and hydrogen (dashed curve) discharge cleaning. This data and the absolute charge-exchange flux indicate that for oxygen discharge cleaning the neutral atom density, while initially higher, is a factor of ~3 lower for the bulk of the shot duration. Oxygen discharge cleaning also leads to reduced C III impurity light intensity, oxygen line intensities about the same, increased electron and ion temperatures, and increased discharge current operation.

Toroidal Field Variation: The ORMAK toroidal field has been increased from a maximum of 18 kG to 25 kG currently. The higher toroidal field has led to improved confinement, higher electron and ion temperatures, and an increased distinction between the type A and type B modes discussed previously. [1] Figure 2 shows the divergence of the high density branch (type A, large amplitude m = 2 MHD code, peaked $T_e(r)$ profile) with increasing toroidal field obtained for essentially constant filling pressures and toroidal currents.

High Discharge Current Behavior: Oxygen discharge cleaning has permitted relatively long duration shots at currents up to 200 kA. These high current (180-200 kA) discharges rise to ~90% peak value in ~30 ms and remain within 10% of peak value for ~30 ms before decaying smoothly. The central electron temperatures (>1 keV) are increasing with currents ($\sim I^{1/2}$), and

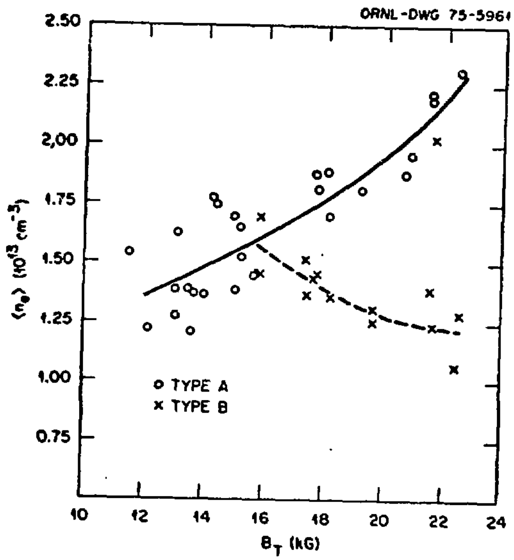

Fig. 2. Separation of Type A and Type B Modes with B_T.

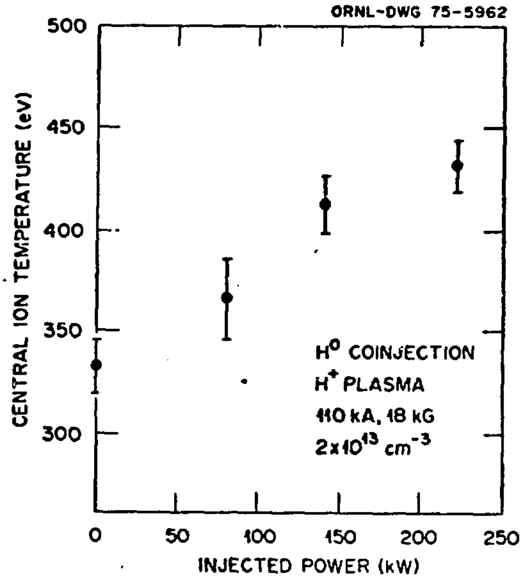

Fig. 3. $T_i(0)$ Scaling with Injected Power.

initial ion temperature increases as $I^{1/3}$ or slower. The scaling of $\beta_p \sim \bar{n}_e/I$ continues to hold.

Neutral Beam Injection Experiments: Injection experiments since the Tokyo IAEA conference have principally been addressed to two main questions: (1) ion temperature scaling with increasing injection power and (2) improvement of counterinjection heating efficiency and reduction of plasma deterioration with increasing toroidal current. Figure 3 shows that for nearly constant plasma conditions, the ion temperature rises approximately linearly with coinjected power with no real evidence yet for saturation. Figure 4 shows the effect of increasing coinjected power on the electron temperature profile. For 65 kW D^0 injection the central T_e rises but the volume average remains at 410 eV. For 165 kW D^0 coinjection the $T_e(r)$ distribution broadens and the volume-average T_e rises to 500 eV.

Counterinjection Improvement with Toroidal Current: At 95 kA only about 1/5 as many counterinjected fast ions scatter through 90° in pitch angle as coinjected ions, resulting in no appreciable net ion heating, a reduction in central electron temperature and generally destabilizing behavior. At 155 kA, about 1/2 as many counterinjected fast ions scatter through 90° as coinjected ions, resulting in 45% to 60% as much ion heating as for coinjection. This is expected since the fast ion loss depends on the poloidal ion gyroradius so that the energy for which a given loss occurs increases as I_T^2. Similarly, central electron temperature is no longer lowered and no appreciable adverse effect on plasma stability is observed. Figure 5 shows the improvement with toroidal current of the ratios (counterinjection)/(no injection) for several parameters (V, $T_e(0)$, and C III line intensity).

References:

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[1] L. A. Berry et al., IAEA Tokyo Paper IAEA-CN-33/A5-1 (1974).

[2] L. A. Berry et al., IAEA Tokyo Paper IAEA-CN-33/A5-2 (1974).

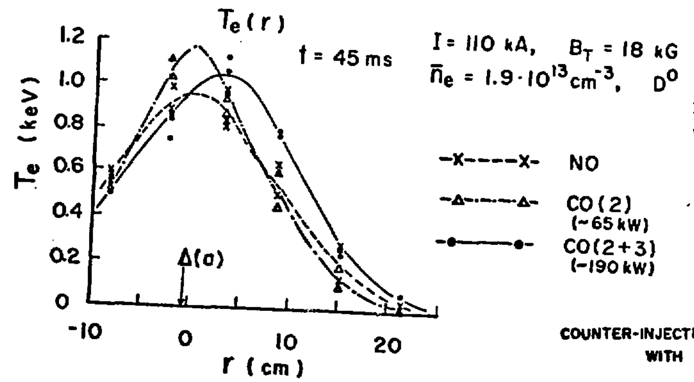

Fig. 4. Relative Improvement of Counterinjection with Toroidal current.

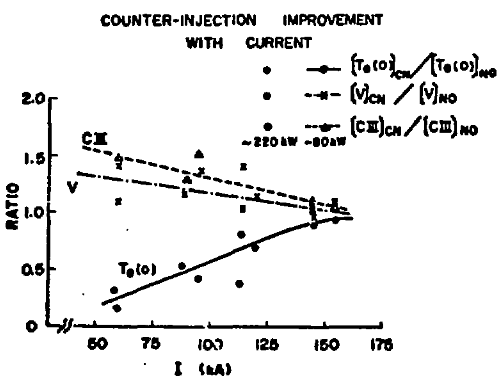

Fig. 5. Effect of Increasing Coinjection Power on $T_e(r)$.