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BIASING EXPERIMENTS ON THE ATF TORSATRON*

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Introduction

Recent biasing experiments[1] on tokamaks have been very successful in improving the global particle (H-mode–like) confinement resulting from the setup of an outward-pointing radial electric field at the edge. These experiments have been extended to the current-free Advanced Toroidal Facility[2] (ATF), and initial biasing experiments have been carried out in electron-cyclotron-heated (ECH) plasmas. ATF has a torsatron configuration with $l = 2$, 12 field periods ($M = 12$), a major radius $R_0 = 2.1$ m, and an average plasma radius $a = 0.27$ m. The current-free magnetic configuration of ATF that is produced by external means has moderate shear; the rotational transform ($\iota = 1/q$, where q is the safety factor) at the last closed flux surface (LCFS) is $\iota \approx 1$, which is about a factor of 3 higher than the central value. ECH plasmas are created at a magnetic field $B = 0.95$ T using a 53-GHz gyrotron source with heating power up to $P \sim 400$ kW. In these ECH plasmas, a representative line-averaged plasma density is $\bar{n}_e \sim 5 \times 10^{12}$ cm^{-3}, and the plasma stored energy $W_p \approx 2$ kJ. A pair of rail limiters,[3] which are normally floating, one at the top and one at the bottom of the device, are biased at positive and negative potentials with respect to the vessel.

Biasing Setup

These initial experiments were carried out by placing the limiters, which are not on the same field line, near the LCFS, where the normalized radius in flux coordinates is $\rho = r/a \approx 1$. The poloidal cross section of the plasma varies with the toroidal angle φ. At the locations of the limiters, $\varphi = 0°$ and $30°$, the plasma cross section is vertically elongated (almost elliptical); at $\varphi = 15°$, it is horizontally elongated.[2] Here, the limiters are considered as electrodes for biasing because their particle flux coverage is only ~18%, owing to their small physical size and to the low q value, $q \sim 1$, at the edge.[3] The limiters do not affect the edge plasma potential profile when they are floating. For the biasing, a 72-kW DC power supply that can deliver a maximum output voltage of 120 V is used.

Experimental Results

When the limiters are positively biased at 120 V with respect to the vacuum chamber, and keeping the gas feed constant [Fig. 1(a)] the line-averaged plasma density increases by about

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factor of 3 from the value when the limiters are floating and reaches the cutoff density of the electron cyclotron heating at the second harmonic resonance, ~10^{13} cm^{-3}; this occurs at time $t_c \sim 0.125$ s. At the same time, a drop in the intensity of the H_α radiation, I_{H_α}, from both the limiter and the wall indicates that the particle confinement is improving. This is also observed on TEXT with negative biasing.[4] Again relative to the floating case, the plasma stored energy W_p, measured with diamagnetic loops, initially increases along with the density increase but then collapses for a time $t \geq t_c$ after the ECH is cut off.

When the plasma density is controlled with a reduced gas input, Fig. 1(b), further reduction of I_{H_α} and almost no change in W_p are observed. The central electron temperature T_{eo} from the electron cyclotron emission (ECE) measurements shows a drop from 925 eV to about 725 eV at t = 0.3 s; this drop is also measured with Thomson scattering (TS). Measurements from the heavy ion beam probe[5] (HIBP) and the fast reciprocating Langmuir probe[6] (FRLP) indicate that the plasma potential Φ at the edge, $\rho = 1$, is increased by ~100 V, Fig. 2, as a result of the shift in the peak of Φ from outside the edge, $\rho \sim 1.1$, toward the inside. This spatial shift in Φ results in a change in the sign of the radial electric field E_r at $\rho \geq 1$ from inward to outward, $E_r \approx 20$ V/cm. As observed in earlier edge turbulence studies on ATF, the peak of Φ is related to the location of the shear layer of the poloidal phase velocity of the electrostatic fluctuations.[6] Therefore, positive biasing affects the location of the velocity shear layer and, in turn, the edge fluctuation characteristics, as discussed in detail in Ref. 7. For example, the power spectrum of the fluctuations in electron density $\tilde{n}$ and potential $\tilde{\phi}$ is less broad with the biasing because of the quenching of the high-frequency (>100-kHz) components. The fluctuation levels (rms) $\tilde{n}_{rms}$ and $\tilde{\phi}_{rms}$ are reduced significantly, Fig. 3, with the biasing, and as a result the fluctuation-induced particle flux $\tilde{\Gamma}_r \sim \langle \tilde{n}\tilde{\phi} \rangle$ is also reduced, Fig. 4, by almost an order of magnitude at the LCFS. This is consistent with the observed improvement in $\bar{n}_e/I_{H_\alpha}$ (I_{H_α} from the wall), as shown in Fig. 4, which is related to global particle confinement time. The density profile, Fig. 5, obtained from TS at $t = 0.3$ s shows a higher central value, about a factor of 2, while the edge density as measured with the FRLP drops, indicating a more peaked density profile. The n_eT_e profile remains approximately the same with biasing, consistent with W_p measurements. Power deposition on the limiters is also reduced, by about a factor of 6, and this further indicates that the particle heat flux to the limiters is reduced as the result of improved particle confinement.

Discussion

Even though global particle confinement improves with positive biasing, almost no improvement in the energy confinement is observed. This result is similar to that discussed by Taylor et al. in Ref. 1. The negative biasing (so far, up to –120 V) yielded some reduction of $\bar{n}_e$ and W_p with constant gas feed. At the same time, measurements of the edge potential profile indicate almost no significant change with negative biasing of the limiters. Biasing caused almost no increase in the iron impurity signal from the plasma center and the oxygen impurity signal from the edge. These experiments will be extended to higher biasing voltage (~300 V) in the future.

Acknowledgements

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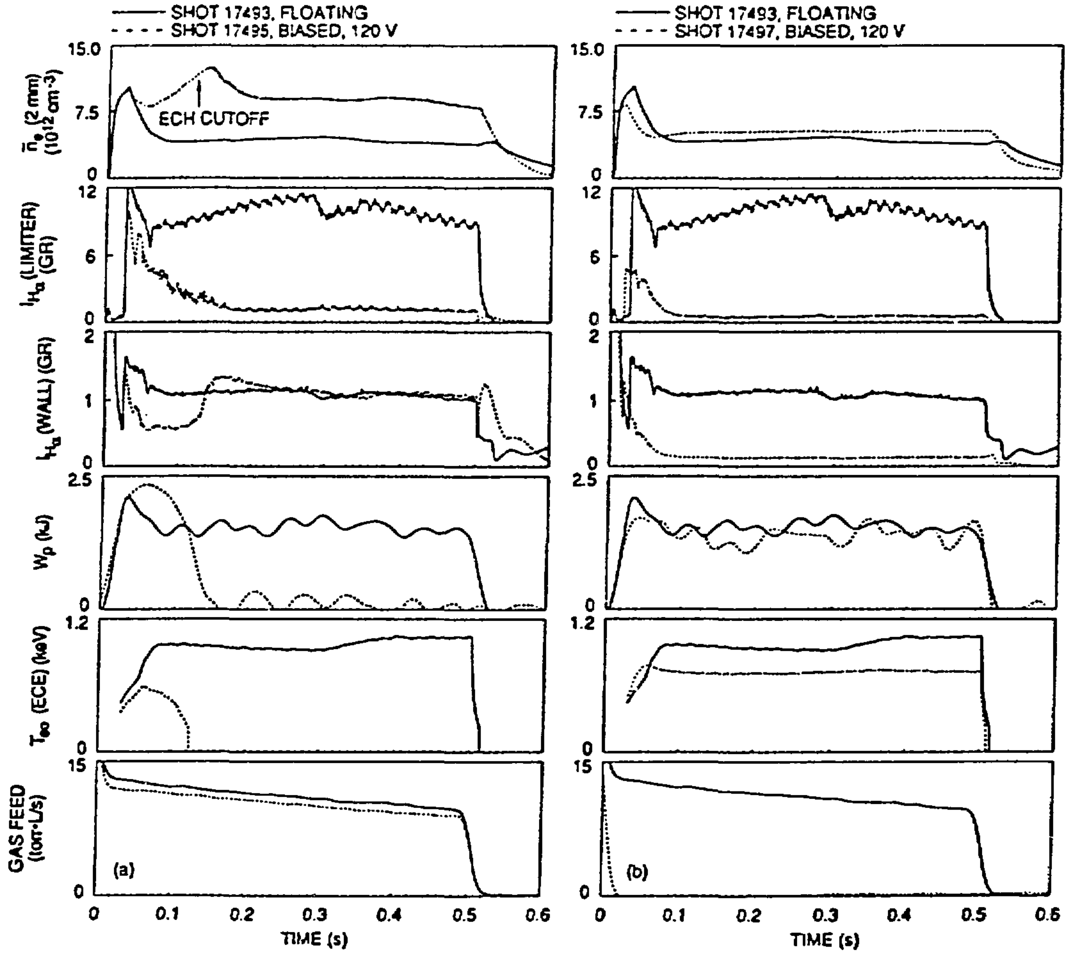

Fig. 1 Time evolution of plasma parameters ($\bar{n}_e$, H_α signals, W_p, and T_{e0}) for floating limiter, shot 17493, and biased (120-V) limiter, shots 17495 and 17497, for (a) constant gas feed and (b) constant density. The ECH cutoff for shot 17495 is indicated; at this time, the plasma collapses.

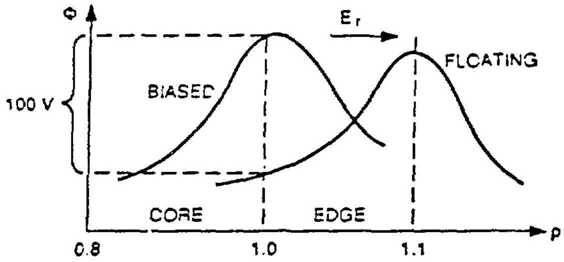

Fig. 2 *Plasma potential, Φ, profile measured with HIBP at the edge for the floating and biased limiter cases for constant* $\bar{n}_e$.

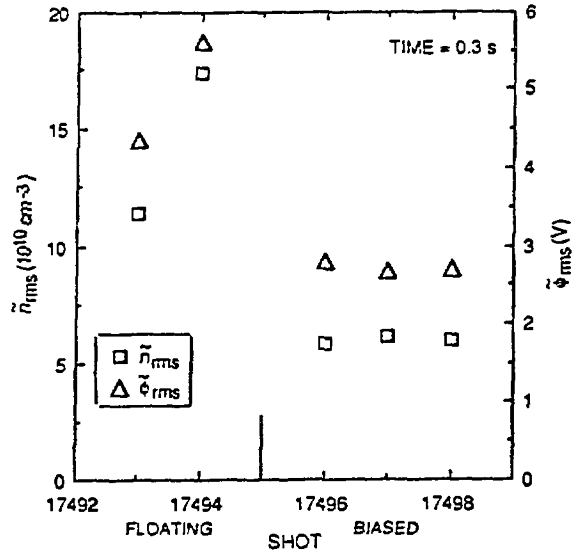

Fig. 3 Fluctuation levels (rms) of density $\tilde{n}_{\rm rms}$ and potential $\tilde{\phi}_{\rm rms}$ for the floating and biased limiter cases for constant $\bar{n}_e$.

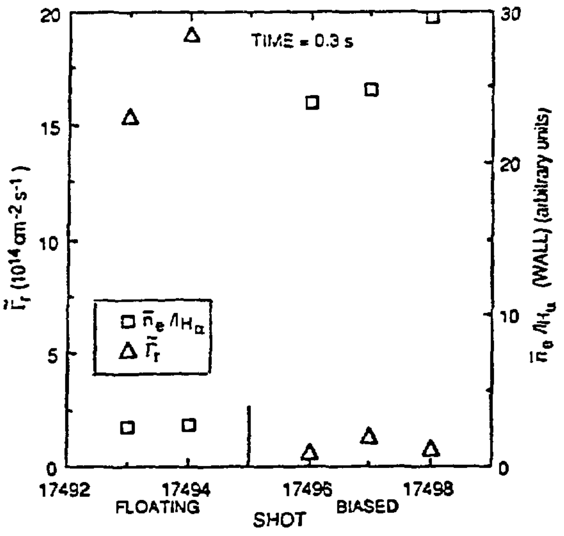

Fig. 4 Fluctuation-induced flux $\tilde{\Gamma}_r$ and $\bar{n}_e/I_{\mathrm{H}_\alpha}$(wall) for the floating and biased limiter cases for constant $\bar{n}_e$.

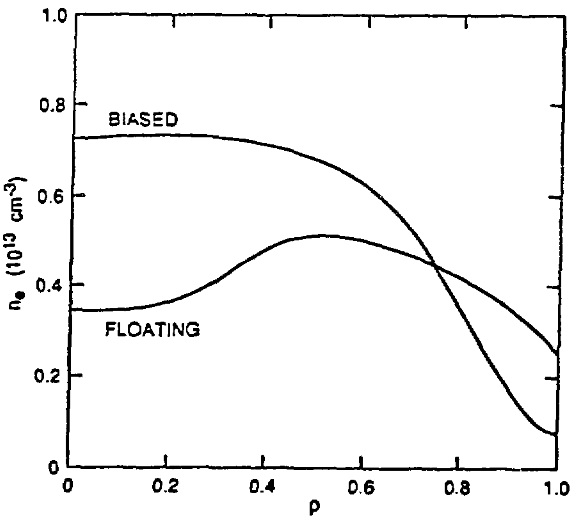

Fig. 5. Density profile obtained from the Thomson scattering measurements for the floating and biased limiter cases when the plasma density is kept constant.