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# ACTIVE PROBING OF PLASMA EDGE TURBULENCE AND FEEDBACK STUDIES ON THE TEXAS EXPERIMENTAL TOKAMAK (TEXT)

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## Introduction

The edge fluctuations play a critical role in the overall tokamak confinement.[1] Experiments on TEXT show that electrostatic fluctuations in the edge plasma are the dominant mechanism for energy and particle transport.[2] The basic mechanisms responsible for the edge turbulence are the subject of ongoing research in fusion devices. To understand the driving forces responsible for edge fluctuations, a novel experiment is underway on TEXT to actively modify the turbulence at the plasma edge by launching waves using electrostatic probes in the shadow of the limiter. This technique permits active probing of the spectral properties of the edge turbulence. This new approach to the study of edge fluctuations can provide more insight into the basic dynamics of the turbulence and may, in turn, enable detailed comparison with the theory. These experiments, which rely on the use of oscillating electric fields at the plasma edge, complement edge fluctuation control studies that are presently limited to the use of applied dc biasing to influence the edge electric field profile.[3] These experiments have been extended to control of the edge plasma fluctuation level, using feedback to explore its effects on the edge turbulence characteristics as well as on confinement.

## Experimental Arrangement and Diagnostics

The experiments are carried out with a wave launching system consisting of two Langmuir probes ($L_1$, $L_2$) which are separated by $d = \lambda/2 \sim 1.8$ cm, where $\lambda$ is the wavelength of the electrostatic edge fluctuations, in the poloidal direction with respect to the toroidal magnetic field, $B$. The $L_1$, $L_2$ are operated in the electron side of the (I,V) characteristic. Each probe tip is fed separately by independent ac power supplies capable of providing up to 1.5 kW of power in the frequency range of 9 to 250 kHz. The power sources are driven by a signal generator through a phase shifter, which allows control of the ac phase difference $\Delta\varphi_{12}$ between the $L_1$ and $L_2$, and a band pass filter (BPF), as shown schematically in Fig. 1.

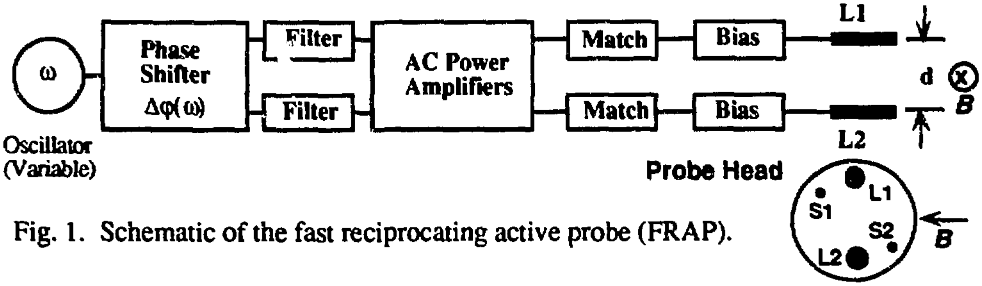

Fig. 1. Schematic of the fast reciprocating active probe (FRAP).

The $L_1$, $L_2$ are designed to handle an ac probe current of up to $\tilde{I}_{ac} \sim 15$ A, which corresponds to ~30% of the estimated total fluctuation current within the correlation volume of edge plasma that has relative density fluctuations of $\tilde{n}/n \sim 20\%$ at typical averaged frequency of $f = \omega/2\pi \sim 50$ kHz.[2] Besides these wave-launching (or exciting) tips there are two small probe tips ($S_1$, $S_2$) separated by $d/2$ placed on the same probe head (see Fig. 1) to measure the local plasma floating potential, $\phi_f$. One of these tips, $S_1$, is utilized for feedback experiments to provide the input signal for driving the $L_1$ and $L_2$. This launcher system is called the fast reciprocating active probe (FRAP) because of its fast plunging action into plasma, which takes about 50 ms for a 5-cm stroke, to reduce the heat load on the probes during the discharge. The specific edge fluctuation diagnostics used for these experiments are a fast reciprocating Langmuir probe

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(FRLP) array[4], used as sensing probe, located halfway around the torus from FRAP, separated by ~157° toroidally, and two sets of fast $H_\alpha$ radiation measuring arrays[5].

## Experimental Observations

### a. Active probing of edge turbulence

The series of active probing experiments are carried out by launching waves from FRAP in ohmically heated plasmas with a flat top of ~300 ms in hydrogenic discharges. The toroidal magnetic field is $B \sim 2.1$ T; the average plasma density is $\bar{n}_e \sim 3 \times 10^{13}$ cm$^{-3}$. The rail limiters (top, bottom, and outside) are located at $r_a = 27$ cm, while FRAP is at $r \simeq 27.5$ cm on the machine top. The following experiments are performed with FRAP ac current $\tilde{I}_{ac} \sim 5$–$8$ A in the frequency range of 15 to 50 kHz with broadband BPF settings. Measurements of potential *fluctuations* $\tilde{\phi}_f$ *from FRLP indicate that the excited* waves are received by FRLP, which is located $r = 27.5$ cm at the bottom of the torus. For example, in Fig. 2, the FFT of $f = 30$ kHz signal launched from FRAP is shown together with the fast Fourier transform (FFT) of the received signal $\tilde{\phi}_f$, which is about 25 dB above the background fluctuations level. This experiment is performed with a plasma current of $I_p = 180$ kA corresponding to an edge safety factor of $q = 4.3$ at $r = 27.5$ cm . Earlier experiments[6] indicated that for $q = 4.3$ FRAP and FRLP have measured the highest turbulence coherence, and at the same time the magnetic field line (FL) plots show that these probes and one of the $H_\alpha$ arrays (located at P1) are all on the same magnetic flux tube, while the second $H_\alpha$ array (located at P14) 's not. For this experiment the measured traveling time of the wave is $t_d \sim 0.2$ ms from FRAP to FRLP. Given the distance along the field line, $L_\| \sim 12$ m, it is estimated that these waves have a speed of $v_\| = L_\|/t_d \sim 5 \times 10^6$ cm/s which is about the ion sound speed $c_s$ for $T_e \sim 25$ eV edge plasma. The detected signal strength of $\tilde{\phi}_f$ weakly depends on the frequency of the wave, the plasma current, and the phasing of the applied ac signal between $L_1$ and $L_2$. It is observed that for $f = 15$-$25$ kHz the amplitude of $\tilde{\phi}_f$ is slightly higher, by about factor of 1.5, than the rest of the frequencies used (15 to 50 kHz) during these experiments. The effect of $I_p$ on $\tilde{\phi}_f$ measured at the launching frequency of ~30 kHz is shown in Fig. 3(a), and the intensity of the fluctuating $H_\alpha$ radiation,

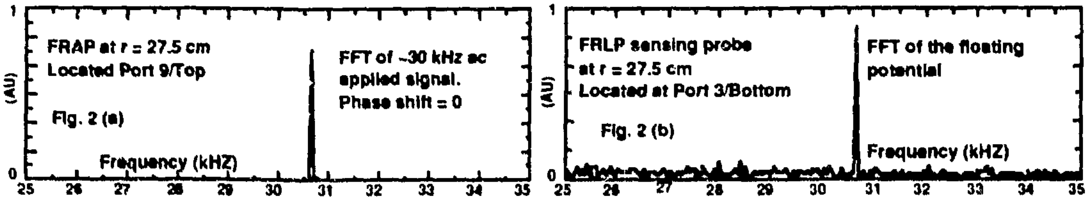

Fig. 2. (a) The 30 kHz injected signal from FRAP, r = 27.5 cm, (b) received by the sensing probe FRLP, r = 27.5 cm, located halfway around the torus from FRAP.

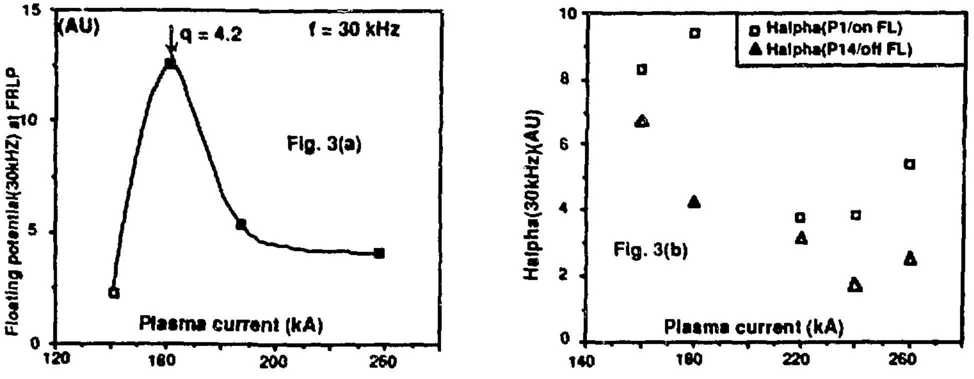

Fig. 3. (a) The effect of plasma current $I_p$ on $\tilde{\phi}_f$ measured at the launching frequency of ~30 kHz is shown. (b) The intensity of the fluctuating $H_\alpha$ radiation, $\tilde{I}_\alpha$, from the two arrays (port P1 is on the same FL with FRAP for q ~ 4.3, but port P14 is not) is plotted.

$\tilde{I}_\alpha$, from the two arrays is plotted in Fig. 3(b). The $\tilde{I}_\alpha$ from both arrays has similar dependence on the plasma current. This observation may suggest excitations of these waves on the flux surface rather than on the flux tube. The radial extent of the wave is also measured by scanning FRLP. The signal strength of $\tilde{\phi}_f$ from FRLP is shown in Fig. 4 as a function of the radial position of FRLP. It is observed that the excited wave penetrates into the core plasma even though it is being launched from ~0.5 cm behind the limiter, and $\tilde{\phi}_f$ has ~2 cm of radial width. This result indicates that by actively perturbing the edge plasma fluctuations from the limiter shadow, it may be possible to influence the core plasma characteristics inside the limiter. The ac phase shift $\Delta\varphi_{12}$ between $L_1$ and $L_2$ is also varied, and the result is given in Fig. 5. The $\tilde{\phi}_f$ measured with FRLP is about a factor of two higher when $\Delta\varphi_{12} = 0$. At the same time, modifications to the frequency spectrum of the poloidal wavenumber $k_\theta$, Fig. 6(a), the fluctuations of the edge density, Fig. 6(b), and the plasma potential, Fig. 6(c), are observed at the launching frequency of $f \sim 30$ kHz. For example, at $f \sim 30$ kHz, $\tilde{n}$(ac on)/$\tilde{n}$(ac off) ~ 2, while $\tilde{\phi}$(ac on)/$\tilde{\phi}$(ac off) ~ $k_\theta$(ac off)/$k_\theta$(ac on) ~ 5, which is consistent with the predictions of the simple mixing length theory.[7]

### b. Feedback experiments

When the launcher is driven by the floating potential fluctuations, sensed by $S_1$ and used as an input to the system through the BPF = 10–30 kHz at the location of FRAP, the edge fluctuations can be suppressed (≤ 40 kHz), without enhancing other modes, or excited (~10 kHz), depending on $\Delta\varphi_{12}$, both locally and at the downstream sensing probe, FRLP. This feedback arrangement is similar to the ones used on earlier experiments.[8] The results are shown in Fig. 7(a), obtained from the FRAP sensing tip $S_2$, and Fig. 7(b), obtained from FRLP. These measurements indicate that the feedback affects the fluctuations not only locally but also halfway around the torus. The estimated fluctuation-induced radial particle flux $\tilde{\Gamma}$ also varies with $\Delta\varphi_{12}$. For example, $\tilde{\Gamma}$ is ~20% higher without the feedback when $\Delta\varphi_{12} = 0$, but it becomes ~20% lower when $\Delta\varphi_{12} = \pi/2$. The global core plasma parameters have not been affected by the feedback except for slight variations on the edge $n_e$ and $T_e$.

## Discussion

These preliminary observations have successfully demonstrated the feasibility of exciting waves at the plasma edge to actively probe the spectral properties of the edge turbulence. The initial feedback trials are also encouraging for controlling edge turbulence. Using these initial observations detailed experiments are planned at various feedback gain and phase shift settings for the upcoming TEXT-U with additional sensing probes located at various locations around the torus. The poloidal extent of the feedback excitations will also be investigated. Meanwhile, detailed data interpretation and modelling studies are underway.

## Acknowledgements

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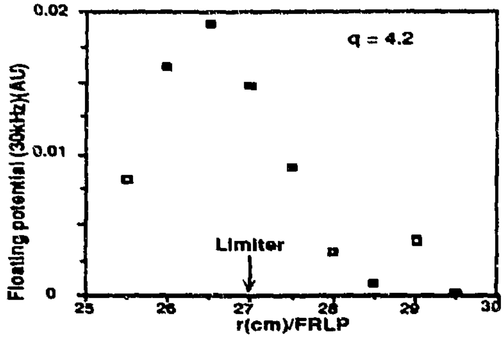

Fig. 4. The signal strength of $\tilde{\phi}_f$ from FRLP is shown as a function of the radial position of FRLP.

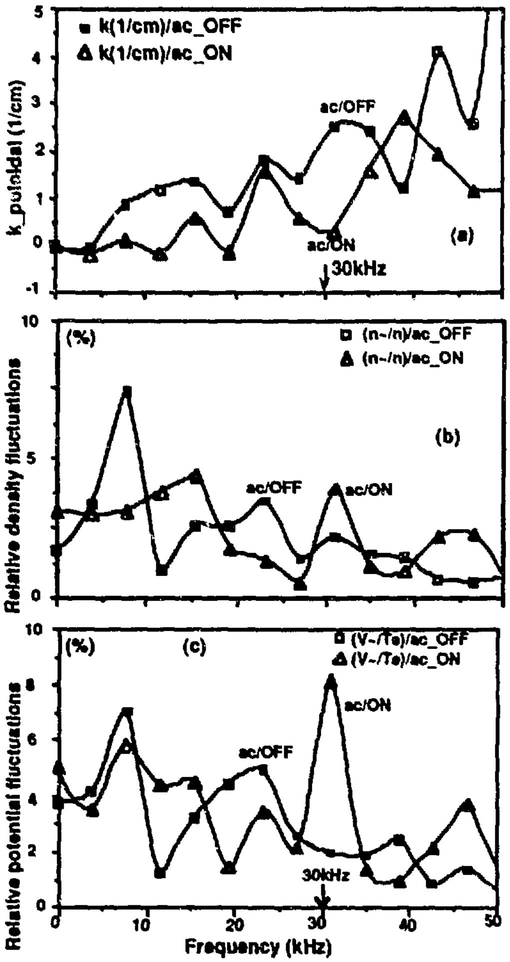

Fig. 6. (a) Spectrum of the wavenumber; (b) spectrum of the normalized density fluctuations; (c) spectrum of the plasma potential fluctuations normalized to $T_e$ are shown for zero phase shift, $\Delta\varphi_{12} = 0$.

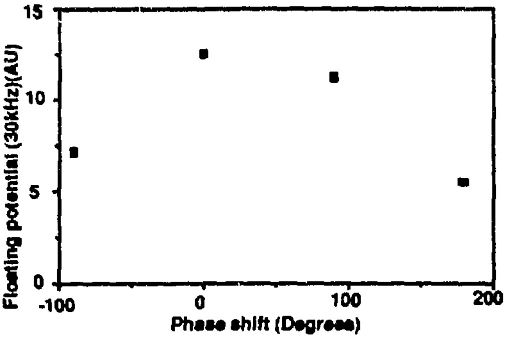

Fig. 5. The effects ac phase shift $\Delta\varphi_{12}$ between the $L_1$ and $L_2$ on the signal strength of $\tilde{\phi}_f$ from FRLP is shown.

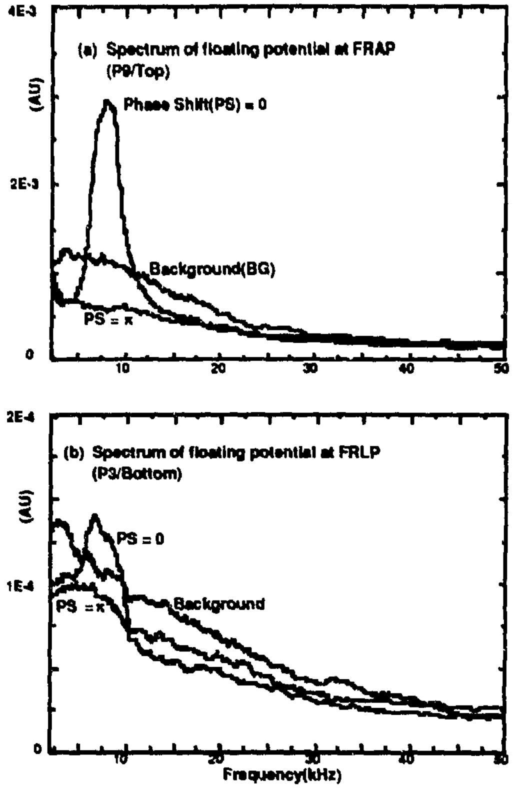

Fig. 7. Effects of feedback on the potential fluctuations spectrum measured at (a) FRAP and also at (b) FRLP for the phase shift settings of $\Delta\varphi_{12} = 0$ and $\pi$ compared to no feedback case (BG) are shown.