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Effects of flush-mounted probe bias on local turbulent fluctuations

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Abstract

Recent measurements on Alcator C-Mod explore the reliability of fluctuation measurements made with surface-mounted probe triplets in the divertor region. The normal configuration of each triplet consists of one angled probe operating as a swept tip and two nearby flush tips measuring floating potential fluctuations. In this mode, changes in the floating potential fluctuation levels and spectra have been observed which correlate to the level of current collected by the swept tip. The disturbance amplitude falls off with distance from the source probe, as well as with increasing electron density. The observed fluctuation changes are likely related to the low frequency plasma potential changes induced by the neighboring probe bias. An understanding of these observations is essential to interpretation of fluctuation measurements in any high-density divertor region. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Alcator C-Mod; Scrape-off layer

1. Introduction

Flush mounted probes have become standard diagnostics in the edge and divertor regions of tokamaks. Detailed analysis of data from these probes, however, is often not performed due to the many complications caused by the magnetic geometry and proximity to a conducting surface. Fluctuation measurements in particular are typically not utilized. Given both the preponderance of available data and the importance of divertor and edge phenomena to overall plasma confinement, experiments are underway on Alcator C-Mod [1] to determine the viability of probes mounted in the divertor surface as plasma fluctuation diagnostics. While there has been some success in observing the fluctuation spectra with these probes and matching them with observations on other tokamaks [2], some features occur in the data which suggest that the effects of flush-mounted probes on the local plasma potential play a role in the fluctuations observed with these probes.

Triplets of probes on the inner and outer divertor plates of C-Mod provide routine temperature and density data through a single swept probe technique. During experiments aimed at measuring fluctuation-induced fluxes with these triplets, it was observed that potential fluctuation levels on a floating probe are affected by the probe bias sweep on a neighboring probe. Further investigation of this phenomenon reveals that it is spatially localized with a spread of approximately 0.4 mm across the magnetic field, it has an amplitude determined directly by the current collected by the swept probe, and it increases in strength inversely with the plasma electron density. In some low density cases, a decrease in fluctuation level relative to the background is seen when the biased probe is in ion collection. The following sections will describe the observations in detail, discuss possible explanations, and comment on relevance to divertor probes and biased electrode experiments in general.

2. Description of experiment

Fig. 1 is a diagram of the C-Mod divertor region showing the location of each probe triplet. The inset

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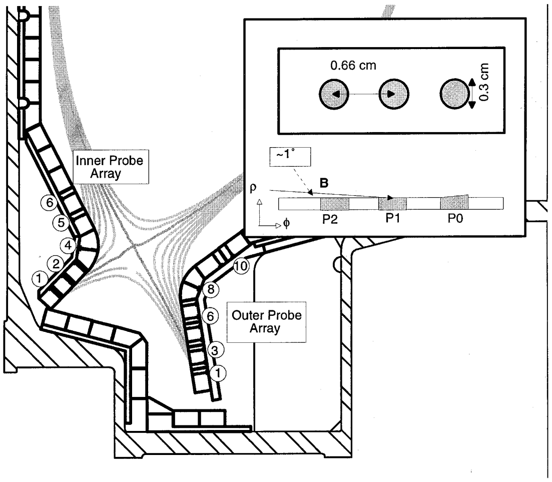

Fig. 1. Cross-section of the Alcator C-Mod divertor region, showing the location of the FMP triplets. *Inset*: detail of a flush-mounted probe triplet.

details the geometry of the three tips. Tip P0 is angled at 11° to the divertor surface to increase the area of intersection with the magnetic field, and the other two probes (P1 and P2) are flush mounted. The swept probe angle reduces the effects of grazing angles on the current-voltage characteristic analysis [3]. All of the probes and the divertor surface tiles are molybdenum. For the experiments detailed here, the two flush tips are configured to measure floating potential and the angled probe is swept from −100 to +20 volts at 50 Hz. All probe biasing is controlled electronically, allowing modification of the measurement state at each probe and of the sweep waveform. Plasma fluctuations are measured at selected triplets with a bandwidth of up to 2.5 MHz.

The angle of intersection of the magnetic field with the (non-angled) probe surfaces varies from 1.5° in the far SOL region to a minimum of 0.4° near the separatrix strike point. This translates to an effective (perpendicular to the magnetic field) probe area of approximately 1.45 mm^2 for the angled tip and 0.105 mm^2 for the flush tips. Connection lengths along the magnetic field between the outer divertor and inner divertor range from 4 m in the private flux region to greater than 20 m in the SOL, while the electron-ion mean free path for a typical discharge is 1–10 cm at the divertor surface, so short connection length effects are likely not significant.

3. Analysis

Fluctuation level changes at floating tips P1 and P2 have been linked to the current to the swept bias on tip P0 for all of the triplets that have been studied, including triplets 3–8 on the outside divertor and probes 4 and 6 on the inside divertor. The spectral changes are not symmetric around zero current, with stronger effects appearing at lower densities while P0 is biased to collect electrons, and at higher densities while P0 is collecting ions. This analysis will focus on probe 4 on the inside divertor, which demonstrates the most prominent disturbances for the discharges discussed here. Three biasing states for P0 will be considered: electron collection (positive with respect to the divertor surface), ion collection (negative), and zero current (biased to the floating potential).

In order to determine the changes induced in the fluctuation spectra, it is necessary to separate these changes from the turbulent background fluctuations. This has been done by dividing the measured fluctuation time series into realizations based on the current to P0 and performing a Fourier analysis on those realizations. Realizations are chosen to be 0.128 ms to provide effectively stationary data relative to the 50 Hz probe sweep frequency. This procedure was performed on a combination of three shots (360 000 points total at 1 MHz sampling rate) to obtain Fig. 2, which plots the autopower spectra of floating potential fluctuations at P1 while P0 is in electron collection, in ion collection, and at zero current. Large increases (up to an order of magnitude) in fluctuation levels are observed for both ion and electron collection, along with substantial changes in the shape of the spectrum for the ion collection case. The magnitude of the spectral changes relative to the zero-current fluctuation level is approximately linear with the collected current (see Fig. 4). Plasma parameters measured by the swept probe for these three discharges are $n_e \cong 4 \times 10^{20}\ \text{m}^{-3}$ and $T_e \cong 5$ eV.

Fig. 3 plots coherence and phase between P1 and P2 for the same three collected bias levels. The coherence increases to near one over frequencies below 100 kHz for P0 in electron collection and decreases at low frequencies for ion collection. The phase shift is similar for the

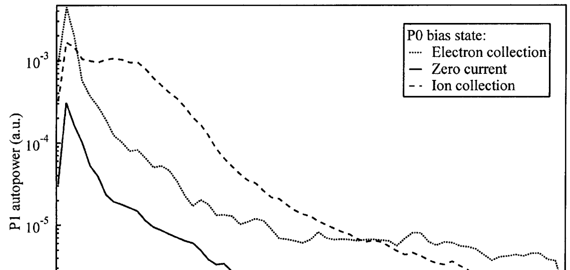

Fig. 2. Autopower spectra of $\tilde{V}_{fl}$ at P1 illustrating the effects of different collected currents at P0.

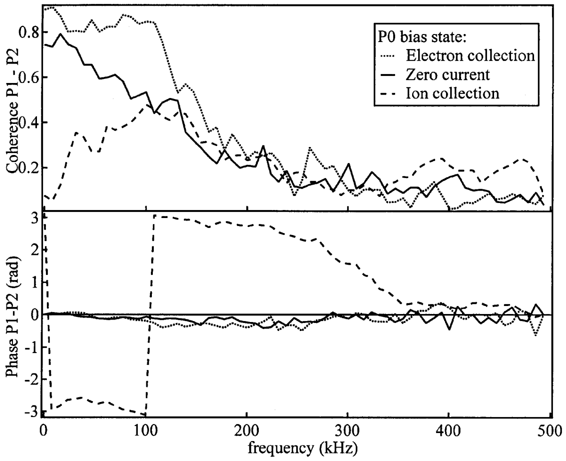

Fig. 3. Coherence and phase between P1 and P2 illustrating the effects of different collected currents at P0.

zero current and electron collection cases and changes dramatically in the ion collection case. Little coherence between the floating potentials and the fluctuations in current to P0 is observed at the zero current and ion collection states. An increase to a coherence of about 0.6 between the P1 floating potential and the P0 current occurs for frequencies below 250 kHz in the electron collection state.

An estimate of the spatial extent of the fluctuation changes can be made from Fig. 4, which shows the RMS fluctuation levels at P1 and P2 as a function of the current collected at P0. Negative current represents electron collection. For the ion collection case, the fluctuation amplitude decreases by approximately a factor of 2 over the 0.1 mm (perpendicular) separation between the tips, implying a width on the order of 0.2 mm perpendicular to **B** for the disturbance, equivalent to about 10 ion gyroradii (or the projected size of the angled tip). For the electron collection case, the disturbance appears to extend further across the field – possibly up to 0.4 mm at the maximum current measured. This measurement does not imply any particular decay rate along the magnetic field, but it is likely that the effect disappears within a finite number of ion-electron mean free paths, consistent with non-fluctuating potential disturbances linked to probes [4]. It would be difficult to observe phenomena on this scale with any diagnostic except Langmuir probes.

The effects of varying plasma density on the RMS level of P1 floating potential fluctuations are show in Fig. 5 for the three P0 bias states. To obtain this plot, realizations were taken from a set of five discharges during which the density changed by a factor of four while the temperature remained approximately constant at 4 eV. The background fluctuation level decreases gradually with increasing density. In the electron collection case, the fluctuation level decreases rapidly with increasing density, and is approximately equal to the background level for $n_e \geqslant 1.5 \times 10^{20}$ m^{-3}. The ion collection case actually has a lower fluctuation level than the background for lower densities, but the level increases to greater than that of the background for $n_e \geqslant 2.5 \times 10^{20}$ m^{-3}. Discharges were not available to examine dependence on edge temperature.

The trends in RMS fluctuation levels illustrated in Figs. 4 and 5 are easily distinguishable above the level of experimental noise in the data. It is important to note, however, that the dependence of these trends on systematic changes in the plasma has not been sufficiently

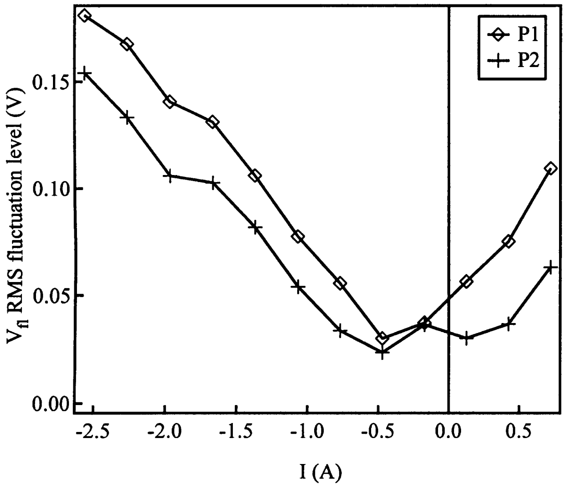

Fig. 4. RMS $\tilde{V}_{\rm fl}$ at P1 and P2 versus current to tip P0. Negative currents represent electron collection and positive currents represent ion collection.

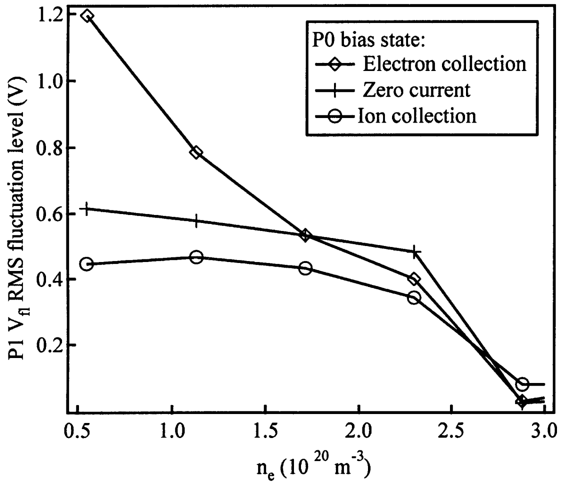

Fig. 5. RMS $\tilde{V}_{\rm fl}$ at P1 versus electron density for positive, negative and zero bias current.

explored, and it is possible that the trends only hold for discharges similar to those presented here. There are a large number of plasma parameters that may effect how the applied potential changes the local fluctuations, such as the background fluctuation level or the local neutral density, and the data thus far analyzed does not provide enough detail to determine the relative importance of various parameters.

4. Discussion

The changes in potential fluctuations due to the swept probe current have only been measured on the most local scale. While observations from an independent diagnostic would be a valuable confirmation, the small spatial scale and rapid spatial decay of the effect may prevent measurement by diagnostics lacking the spatial resolution of Langmuir probes.

The possible explanations to be considered include diagnostic issues (such as electronics noise), changes in the region of plasma sampled by the floating probe caused by the biased probe's effect on local plasma potentials, and instabilities directly generated by the probe interaction with the plasma. The diagnostics issues can be partially addressed: it has been shown that the effect changes with the plasma conditions and decays with distance from the presumed source. This, together with the asymmetry between the ion collection and electron collection cases, allays the suspicion that the fluctuations may be generated independently by the measurement electronics.

It is established in a companion paper that the bias at P0 influences the plasma potential in front of the floating tips [5]. Fig. 6 is a plot of the potential change at P1 and P2 as a function of the current to P0 for one of the discharges used to produce Fig. 3. This potential change will create an $\mathbf{E} \times \mathbf{B}$ rotation in the plasma, possibly changing the spectral characteristics of the turbulence as measured in the affected region. In this case, the observations could not be interpreted as those of a non-perturbing diagnostic.

This potential could also affect the meaning of local measurements through changing the boundary conditions of the plasma. If the presence of a conducting surface has either a stabilizing or de-stabilizing effect on local microinstabilities, then biasing a section of that surface away from its equilibrium state (with regards to sheath potential drop and current flow to the wall) could effect local fluctuation levels. A related example is the electron temperature gradient (or 'sheath') instability, which results from the termination of a plasma with a cross-field potential gradient on a conducting wall [6]. Another mechanism by which the probe bias may affect local fluctuation levels without invoking a specific, probe-related instability is through changing the local plasma potential resulting in a reduction or enhancement of $\mathbf{E} \times \mathbf{B}$ shear stabilization of microinstabilities [7].

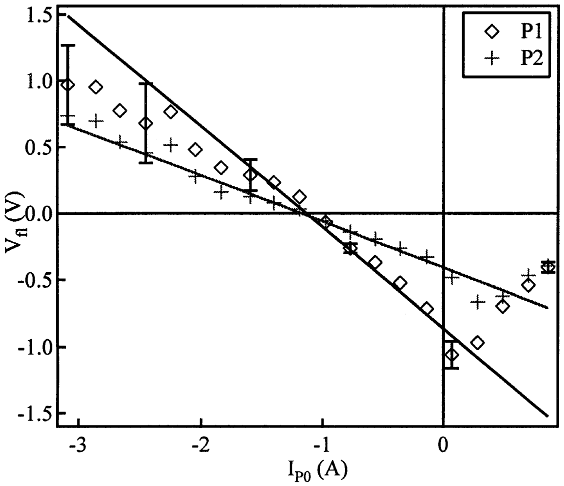

Fig. 6. Average V_{fl} at P1 and P2 plotted against current to biased tip P0. Error bars represent the standard deviation of the average. The linear fit only uses the middle half of the current range.

It is not clear that any of these mechanisms can be applied to the very small spatial scales involved in the observed fluctuations, but they provide a starting point for investigation of the results presented here.

5. Conclusions

Further investigation into the source of the bias-related fluctuations is desirable both to validate background fluctuation studies and to explore the possible relationship between the probe bias and turbulence. It may be possible to link these small-scale measurements with larger biased electrode experiments such as the filamentary density depletion experiments on the LAPD linear device, [8] in which an electrode is used to reduce the plasma density in a localized region resulting in turbulence at the edges of the depletion. Another example is the use of large biased electrodes in tokamaks to generate H-mode-like behavior [9,10]. Comparison to the experiments in a less-complicated geometry or on an intermediate spatial scale could avoid the difficulties with resolving the spatial scale of the disturbance, and at the same time allow a theoretical analysis of the bias and/or current path effects without the complications of background gradients and divertor geometry.

It is important to note that the effects can be subtle relative to a turbulent background plasma, and in some cases may only appear as a change in the tail of the fluctuation spectra. For measurements made in a triple probe configuration where the bias is not swept, this could lead to a systematic error in measurements which require precise knowledge of the fluctuations, such as turbulence-induced flux predictions. At a minimum, such effects should be considered a possible influence on fluctuations measured in close proximity to a biased electrode, regardless of the scale of the electrode.

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