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# TURBULENT FLUCTUATIONS IN THE MAIN CORE OF TFTR PLASMAS WITH NEGATIVE MAGNETIC SHEAR

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## Abstract

### TURBULENT FLUCTUATIONS IN THE MAIN CORE OF TFTR PLASMAS WITH NEGATIVE MAGNETIC SHEAR

Turbulent fluctuations in plasmas with reversed magnetic shear have been investigated in TFTR. Under intense auxiliary heating, these plasmas are observed to bifurcate into two states with different transport properties. In the state with better confinement, it has been found that the level of fluctuations is very small throughout most of the region with negative shear. By contrast, the state with lower confinement is characterized by large bursts of fluctuations which suggest a competition between the driving and the suppression of turbulence. These results are consistent with the suppression of turbulence by the ExB velocity shear.

## 1. Introduction

Recent results [1-4] point to the beneficial effects of negative magnetic shear on plasma performance in tokamaks. In these experiments, magnetic configurations with a non-monotonic safety factor  $q$  have been obtained using a variety of techniques. The common result is a strong peaking of the pressure profile, which indicates a reduction of plasma transport in the central region with negative shear. Since short scale turbulence is considered to be the source of anomalous losses in tokamaks, these results appear to be consistent with theoretical predictions that negative shear can suppress geodesic curvature driven instabilities, such as trapped particle modes [5], the toroidal ion temperature gradient mode [6], and high- $n$  ballooning modes [7].

In order to study the effects of negative magnetic shear on plasma turbulence in tokamaks, we have conducted an experimental study of turbulent fluctuations in plasmas with reversed magnetic shear on the Tokamak Fusion Test Reactor (TFTR) [8]. These are deuterium plasmas with a major radius  $R=2.6$  m, a minor radius  $a=0.94$  m, a toroidal magnetic field  $B=4.6$  T, and a plasma current  $I_p=1.6$  MA. The central plasma region with negative shear is created early in the discharge by a combination of heating and current drive. Under intense auxiliary heating with neutral beam injection (NBI), these plasmas are observed to bifurcate into two different states [3], the reversed shear (RS) and the enhanced reversed shear (ERS) mode (Fig. 1). While the RS mode is similar to the *supershot regime* which is normally observed in TFTR with monotonic  $q$ -profiles, the ERS mode is characterized by highly peaked density and plasma pressure profiles (Fig. 1). Since at the time of bifurcation the  $q$ -profiles are very similar in the two regimes, the observed phenomenon cannot be ascribed solely to the negative magnetic shear.

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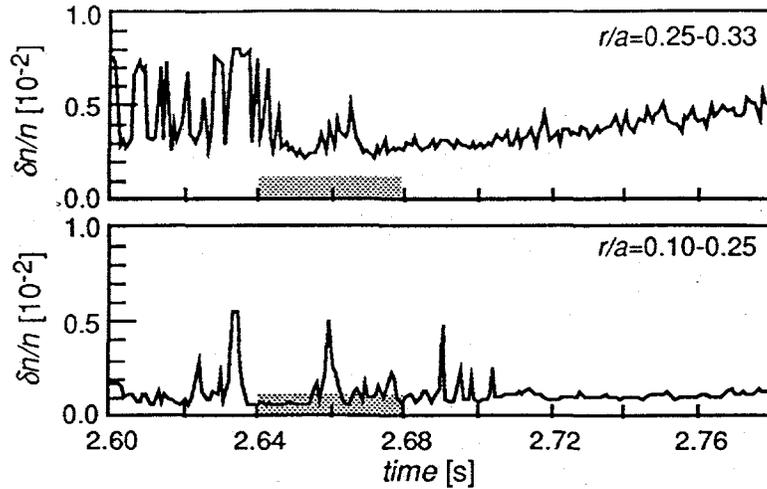


FIG. 3. Time evolution of density fluctuations in the ERS mode. The shaded area represents the time of bifurcation.

By using the displacement of the reflecting point of the probing wave, caused by the plasma density rise, we get the amplitude of density fluctuations shown in Fig. 4 as a function of the normalized minor radius  $r/a$ . The abscissas in this figure are the

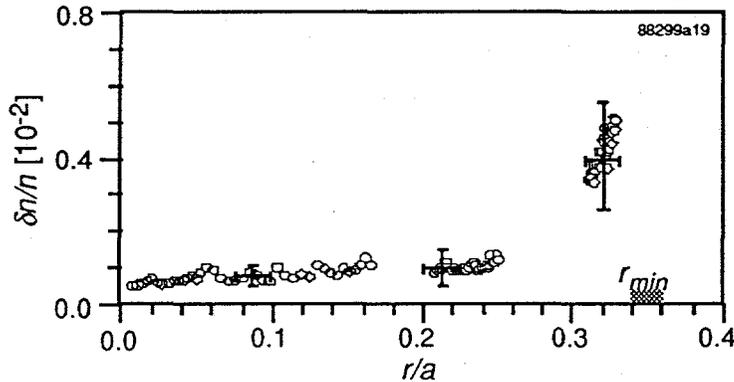


FIG. 4. Amplitude of density fluctuations in the ERS mode of Fig. 1 at  $t=2.72-2.78$  s;  $r_{min}$  is the radial position with minimum  $q$ .

calculated positions of the reflecting cutoff on the low field side of the equatorial plane, including a relativistic correction [10] which ranges from 2 to 6 cm. As described elsewhere [9], to obtain the amplitude of density fluctuations from reflectometry measurements requires the knowledge of the shape of the radial spectrum of fluctuations. Unfortunately, in the rapidly evolving plasmas of the present experiment, this is difficult to obtain with radial correlation measurements. Fortunately, all previous theoretical and experimental studies of short scale fluctuations in large tokamaks indicate that the bulk of the turbulent activity occurs at wavelengths larger than the ion Larmor radius ( $\rho_i$ ), typically in the range of radial wave numbers  $0.2 < k_r \rho_i < 1$ . Accordingly, the values in Fig. 3 and 4 have been obtained assuming  $k_r = 1 \text{ cm}^{-1}$ , which corresponds to  $k_r \rho_i \approx 0.5$ , and we have calculated the error bars by taking the extreme values of  $k_r \rho_i = 0.2$  and 1, respectively. In spite of these uncertainties, we draw the conclusion that the level of fluctuations is very small in the main core of ERS plasmas, and that it rises near the

illustrated in Fig. 6 which shows the time evolution of the electron particle diffusivity and the measured level of turbulence across a back-transition. The latter occurs when, for achieving steady state conditions, the NBI power is lowered from 29 to 15 MW. The three cases shown in Fig. 6 differ on the co-counter NBI power ratio. It has been found [11] that, while balanced injection (case *a* in Fig. 6) and counter-dominated injection produces plasmas which remain in the ERS mode until the end of NBI, co-dominated injection causes a back-transition into the RS mode (cases *b* and *c* in Fig. 6). These data demonstrate very clearly that the loss of ERS confinement, which in Fig. 6 is represented by the rise in the value of  $D_e$ , coincides with a sharp increase in the level of turbulent fluctuations.

### 3. Discussion

We have compared the experimental observations with the theoretical predictions for toroidal electrostatic drift-type modes. Figure 7 shows the linear growth rate of the most unstable mode ( $\gamma$ ) which was calculated with a kinetic toroidal eigenvalue code [12]. Surprisingly, we find the largest values of  $\gamma$  in the ERS mode, which provides further evidence that shear reversal is not the only cause of turbulence suppression in these plasmas. Furthermore, the size of the central stable region is the same in both plasma regimes. These results, which were confirmed by those obtained with a toroidal gyrofluid code [13], demonstrate that other phenomena, besides the reversed shear, play a role in the ERS/RS dynamics.

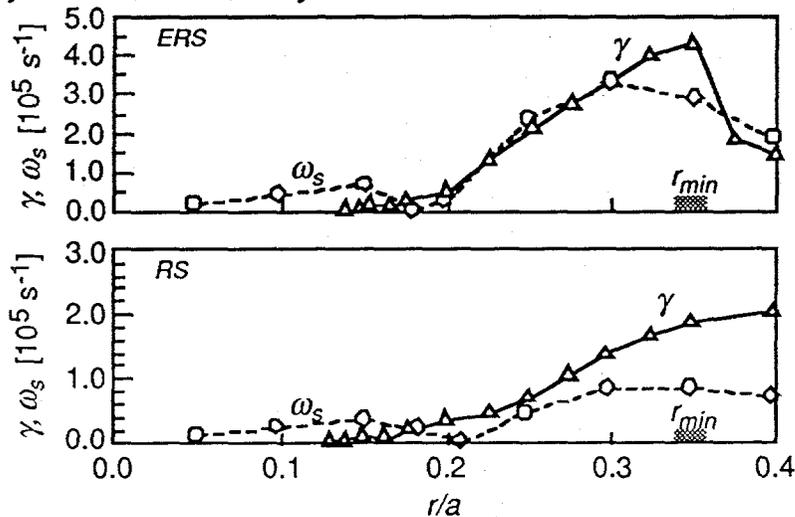


FIG. 7. Calculated values of the maximum linear growth rate  $\gamma$  (triangles), and the shearing rate  $\omega_s$  (circles) for the ERS (top) and the RS (bottom) plasmas of Fig. 1 at  $t=2.75$  s.

A possible mechanism for the suppression of turbulence is the decorrelation of turbulent fluctuations by a large ExB velocity shear which may exist in regions of large pressure gradient [14-22]. This mechanism, which in the past has been invoked for explaining the reduction in the level of fluctuations at the edge of plasmas in the H-mode [14-18], might also be at work in the central plasma region with negative magnetic shear [19-22]. The numerical simulations in Ref. [19] indicate that turbulence is suppressed when the linear growth  $\gamma$  is not larger than a characteristic ExB shearing rate  $\omega_s$ . For this, we may use the expression derived in Ref. [20] which, on the tokamak midplane, gives  $\omega_s = -(RB_\theta/B) \partial(E_r/RB_\theta)/\partial R$ , where  $B_\theta$  is