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Relaxation phenomena during edge plasma biasing in the CASTOR tokamak

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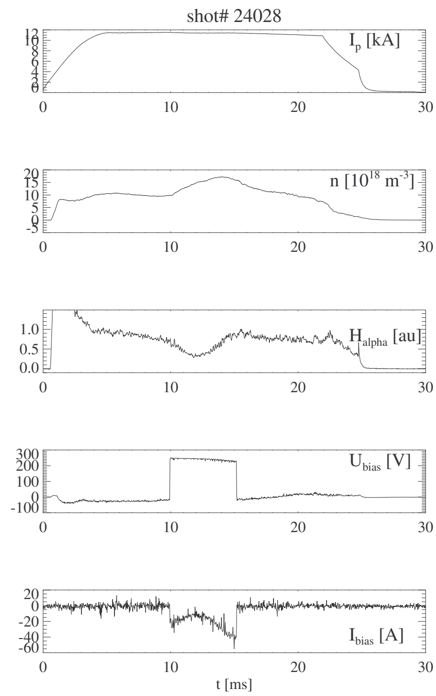
It is recognised that an effective way to control transport in the edge region of fusion experiments is to create a sheared radial electric field. Several experiments have been performed on this field on different magnetic configurations such as tokamak [1], stellarator [2] as well as Reversed Field Pinch [3], usually based on electrodes insertion inside the Last Closed Flux Surface (LCFS).

In the present contribution the first results of biasing experiments performed on the CASTOR tokamak by using a new segmented electrode will be described. CASTOR is a small-size torus with a major radius of 0.4 m and a minor radius of 0.1 m, a toroidal magnetic field of 1.3 T and typical plasma current ranging from 5 to 10 kA, in the present experiment 1 T and 12 kA have been used. The electrode is made of five ring shaped segments, with thickness of 1 mm and 16 mm diameter, radially spaced by 3 mm. The segments can be biased independently up to +300 V with respect to the vacuum vessel, so that a spatial distribution of the biasing voltage can be imposed. The electrode head can be inserted from the top inside the LCFS and different radial positions can be explored on a shot to shot basis. A wide range of experimental conditions have been explored by changing the biased segment(s), the biasing voltage and leaving not used segments either grounded or floating. The most evident effects on main plasma parameters have been observed when at least two of the segments were biased with a bias higher than +250 V, this is probably due to the higher current collected by the electrode head, without clear difference whether other segments were grounded or floating. The edge electrostatic parameters have been monitored by two rake probes, 16 pins each, radially spaced by 2.5 mm and located at the top and at the low field side of the torus. The radial profiles of floating potential, V_f, and ion saturation current, I_s, have been digitized with a sampling rate of 1 MHz and measured on different shots as well as simultaneously by using each second pin during some dedicated shots. In the edge region of the CASTOR tokamak it is reasonably assumed that the electron temperature gradient is negligible so that the gradient of V_f provide a good approximation of radial electric field. In a similar way the ion saturation current gradient give an estimate of the local plasma density gradient [4]. A Gundestrup probe, located at the top of the torus measures the parallel and perpendicular Mach numbers together with the local electron temperature and density; bolometer and UV camera were also available.



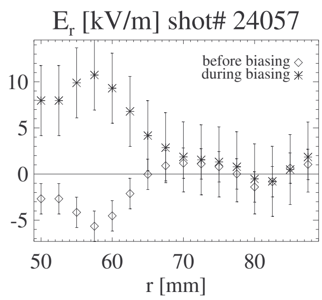


Fig. 2a Average radial profiles of E_r before and during bias.

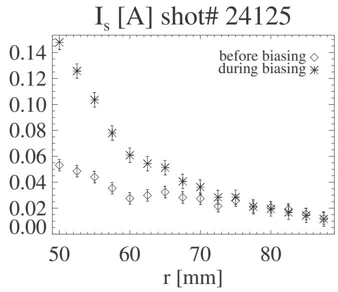


Fig. 2b Average radial profiles of I_s before and during bias.

Fig. 1 Main parameters of shot #24028. Biasing phase from 10 to 15 ms, electrode at r=45 mm.

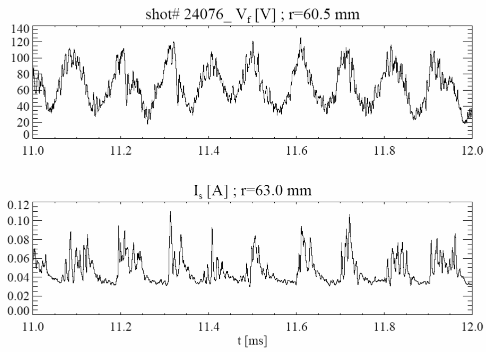


Fig. 3 Relaxation events detected on V_f and I_s signals during biasing phase.

The main plasma parameters during a typical shot are shown in fig. 1, from the top: plasma current, average density, H_α monitor, voltage and current measured on biased segments. During the bias phase, from 10 to 15 ms, a reduction of about a factor 2 of the H_α emission and a corresponding increase of the plasma density have been observed, providing a clear and reproducible indication of a transition to a regime with improved particle confinement. The modifications induced by the electrode bias on the edge radial average profiles of radial electric field, E_r, and ion saturation current are shown in the figures 2a and 2b, r=0 indicates the centre of the poloidal section. It can be observed in fig 2a that during bias a remarkable modification of E_r profile, and therefore of the E×B poloidal velocity, has been achieved in the region r≤65 mm, i.e. within position of the LCFS on the probe location: the bias induced an increase of the E×B velocity, that also changes sign from -5 km/s to 10 km/s, as well as an increase of the associated shear with change of its sign. In particular in the region from r=58 mm to r=68 mm the shear changes from about 0.5 10^6 s^{-1} to -1 10^6 s^{-1}. An increase of flow during bias has also been measured by Gundestrup probe. A strong effect on average profiles is observed also on I_s profiles, which exhibit an almost doubled gradient at the edge. The enhanced confinement regime is then associated to an increase of the radial gradients at the edge, then to a formation of a transport barrier just inside the LCFS.

Focusing on V_f and I_s measurements, during edge biasing and in particular when this enhanced confinement regime is established, strong periodic oscillations have been detected on both quantities with a fairly well defined typical frequency of about 10 kHz. An example is shown in figure 3, where both quantities have been measured simultaneously on the same rake probe by using alternate pins. The V_f and I_s measurements shown in fig 3 are performed at 2.5 mm radially far apart each other, however a quite good correlation can be observed between events detected on both quantities. This quite regular oscillation is radially extended and by looking at the time behaviour of the respective radial profiles it can be observed that these oscillations are the manifestation of fast relaxation of edge profiles after reaching critical gradients: fast relaxation of V_f radial profiles is observed as values of E_r of about 20 kV/m are achieved, whereas in between events density profiles exhibit gradients up to a factor 3 higher than during relaxations. It is worth noting that similar relaxations have been observed also on ISTTOK tokamak during experiments with emissive electrode biasing [5].

During relaxations also a strong change in ion flow can be deduced from Gundestrup probe measurements: the mainly poloidal direction of flow in between relaxation events changes to toroidal direction during the relaxations. This behaviour seems consistent with the decrease of the poloidal E×B velocity during relaxations as deduced by the rake measurements. The described events have been detected also by AXUV bolometer measurements, located on the same poloidal section of the rake probe: these measurements suggest that the relaxations involve a radial region wider than that explored by the rake probe.

The high time and spatial resolution of rake probe measurements allowed a detailed investigation of radial profiles in order to gain insight on typical features characterizing these events. An example is shown in fig.4a where the features of the E_r profile are shown within a time interval of 0.1 ms centred on a peak in the V_f oscillations. It can be seen that high E_r characterize the region r<65 mm and an abrupt change occurs between 10.63 and 10.65 ms.

During this time interval a lower average E_r is found, however strong peak values appear evidencing the onset of an instability, with a characteristic frequency that can be estimated of about 100 kHz and very high local E×B shear up to 1.5 10^6 s^{-1}.

An analogous investigation has been performed on events detected on I_s profiles, that however exhibit a broader and less reproducible behaviour: in order to extract average features on density at the relaxation time occurrence a conditional average analysis has been applied and an example is shown in fig 4b. It can be observed that the maximum of density appears at subsequent times for higher r, so that a radial propagation can be deduced. The relaxation events seem then related to density streams radially propagating towards the first wall, with a radial velocity that can be estimated of the order of 0.4 km/s.

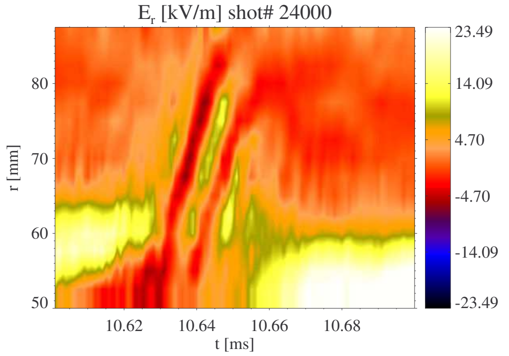


Fig. 4a Time behaviour of E_r radial profile during a relaxation event.

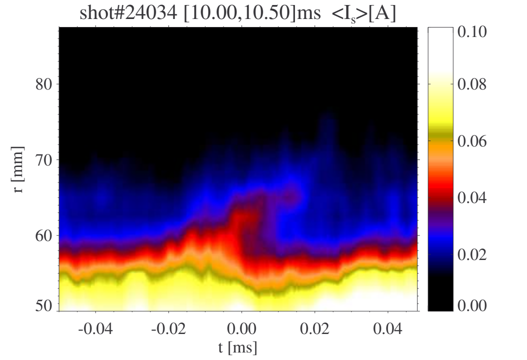


Fig 4b Time behaviour of average radial profile of I_s obtained as conditional average on relaxation events with 0.1 ms time window.

Biasing experiments performed on CASTOR tokamak resulted effective in inducing an improved plasma confinement characterized by the presence of relaxation events. The described events are reminiscent of Edge Localized Modes (ELMs) [6] and given such a similarity this kind of experiment can provide a useful investigation tool for improving understanding of these phenomena, that are believed to play an important role in edge confinement of tokamak experiments [6].

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