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Dynamical control of the convective transport behind a limiter in a magnetized laboratory plasma.

Th. Pierre, A. Escarguel, D. Guyomarc'h, G. Leclert, F. Brochard‡, E. Gravier‡ and P. Devynck†
Lab. PIIM,UMR 6633 CNRS-Université de Provence, 13397 Marseille Cedex 20, France
‡Lab. PMIA,UMR7040 CNRS-Université Henri Poincaré, BP 239, 54506 Vandoeuvre Cedex, France
†Association Euratom-CEA, CEN de Cadarache, 13108 St Paul lez Durance, France

Experiments on the dynamical control of turbulent low frequency waves have been performed in a magnetised laboratory plasma column. The dynamical control (delayed closed-loop feedback) allows for the regularisation of the regime and a significant reduction of the anomalous radial transport.

The experimental setup

Experiments in nonlinear dynamics have been conducted in a new device producing a magnetized plasma (Mistral device). It consists in a large source plasma chamber (140 cm in diameter) connected to a tube (40 cm in diameter, 1 m in length) immersed in a solenoid producing a magnetic field intensity lower than 0.05 T. The linear column is connected to a half toroidal chamber (major radius 60 cm) in which the instabilities induced by the curvature of the field lines can be studied.

The plasma is created by electric discharge in argon or neon gas. A series of 32 filaments are emitting the primary electrons inside the source chamber. The uniformity of the flux of primary electrons is controlled by two compensation coils following a design first used in the device Mirabelle [1]. The neutral pressure (Ar gas) is about 2.10^{-4} mbar. A magnetised plasma column of 30 cm width is obtained inside the tube. During the experiments reported here, the diameter of the plasma column is restricted to 15 cm by inserting a metallic diaphragm at the entrance of the column. The plasma column is axially limited by a collector on the axis at the end of the linear column. Other concentric plates can be biased independently in order to affect the radial electric field.

The typical plasma parameters are as follows: electron density $n_e = 5.10^8 - 5.10^{10}$ cm^{-3}, electron temperature T_e = 2 - 4 eV, ion temperature T_i 0.1 eV, typical electron and ion Larmor radii 0.01 cm and 0.5 cm.

Different types of electric probes are used during the measurements, either separated movable probes or fixed arrays of probes. The fluctuations of the electron saturation current are proportional to the density fluctuations.

From regular to turbulent regimes

Due to the presence of the diaphragm at the entrance of the plasma column, it is possible to study the diffusion or convection mechanisms of the plasma towards the region in the shadow of the limiter, where no ionisation processes exist. A high transparency floating grid is inserted between the source chamber and the magnetised plasma column. Primary electrons overcome the floating potential of the grid and ionise the gas inside the column. The injection of the primary electrons into the column leads to a negative charge on the axis. On the other hand, ions are weakly magnetised and contribute to a radial (outwards) loss of positive charges. The balance between the radial flows of positive and negative charges leads to an equilibrium radial electric field with axial symmetry. Due to the resulting **E×B** drift, electrons and ions drift both in the same direction at the same velocity, leading to an azimuthal convection of the whole plasma. The plasma column rotates as a rigid body if the radial profile of the potential is parabolic. Unstable low-frequency waves are observed in the column when the grid is biased at a negative or floating potential. The potential of the source plasma then acts as a control parameter: a negative bias leads to the instability of the low-frequency waves. At a magnetic field intensity B=0.02 T, a coherent $m = 2$ mode is easily recorded. The transition to the $m = 1$ mode is obtained by decreasing the potential of the source plasma. A further decrease leads to the occurrence of a turbulent state. A similar behaviour has already been reported [2]. The recorded time-series in the shadow of the limiter exhibits a strong intermittency. Figure 1 displays a typical temporal evolution of the plasma density at radial position 15 cm. When the radial position of the probe is changed towards the axis, the intermittent character is progressively lost and a regime similar to spatiotemporal chaos is recorded. The numerical analysis of the time-series of the density just at the edge of the central plasma column leads to the conclusion that the system is not chaotic. The correlation dimension exhibits no saturation though the power spectrum shows that several frequencies are excited simultaneously. In fact, the competition and nonlinear coupling between several modes leads to spatiotemporal chaos. In that case, the numerical analysis restricted to the temporal evolution cannot give a correct description of the complexity.

Dynamical control of the spatiotemporal dynamics

As mentioned before, the rotating plasma column is an extended dynamical system exhibiting spatiotemporal chaos. Is is of great importance to have a dynamical action in order to select a coherent regime using the minimum amount of power. We have chosen to use the Time Delay Autosynchronization method [3] that has been successful in plasma physics in the case of ionisation waves [4] and in the case of low-dimensional chaotic regime of drift waves [5]. In our experimental set-up, the potential of a secondary concentric ring electrode is used as control parameter. The ring is inserted in the shadow of the limiter and the modulation of the potential is changing the radial electric field around the plasma column. The control signal is built subtracting the delayed probe signal from the real time probe signal. The delay is adjusted to the period of the targeted unstable mode. We have chosen to stabilise mode m=2. The transient response after application of the control signal is depicted in figure 2. The probe signal is turbulent before the control and regular after the onset of the control process. It is worth noting that the control signal is not decreasing markedly after the control is switched on. During the regular regime, the system is certainly driven by the closed-loop delayed feedback. The spatiotemporal character of the dynamical regime does not allow a perfect dynamical control using only one sensing point and a global reaction. In further experiments, the control strategy will be changed by inserting an array of sensors and a complex electrode system designed using the results of the detailed analysis of the spatiotemporal dynamics.

The radial modification of the dynamical regime leads to a large variation of the anomalous plasma transport. We have compared the radial density profiles in the case of the coherent and the turbulent regimes. Long time-series are recorded and time-averaged. The radial density profiles in both cases are depicted in figure 3. It is clearly seen that the mean density is higher in the case of a turbulent regime (dotted line) in the shadow of the limiter. The relative variation is shown on the same figure (right) Changing the regime from turbulent to coherent regime induces a strong reduction (30%) of the radial transport.

Conclusion

The magnetized plasma column exhibits turbulent state in a range of control parameter. The system can be regularized using Time Delay Autosynchronisation method (closed delayed feedback). A significant reduction of the anomalous radial transport is obtained when the feedback is active. This result could be extended to the case of the scrape-off layer of tokamaks in order to modify the energy deposition rate on the limiters or alternatively, to drive the build-up of a transport barrier.

References

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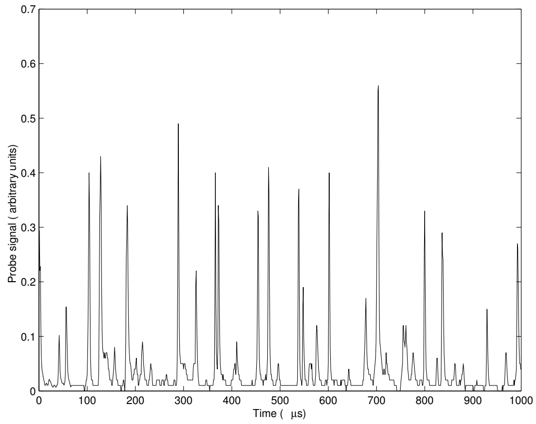

Fig. 1 - Intermittency at the edge of the plasma column.

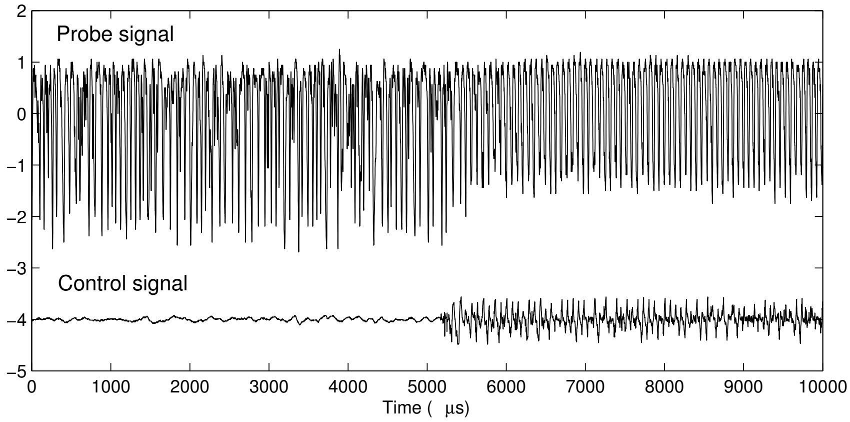

Fig. 2 - Regularisation of the density fluctuations (top trace) after the application of a control signal (bottom trace).

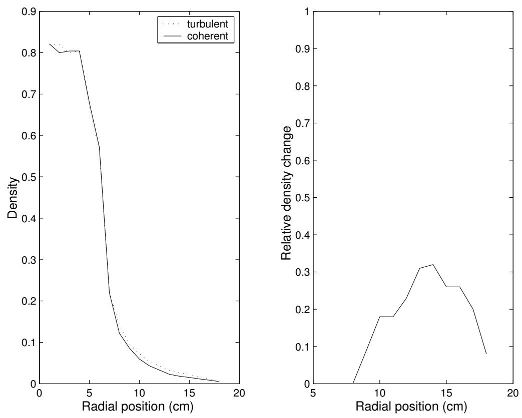

Fig. 3 - Radial profile of the density in the coherent regime (solid line) and in the turbulent regime (dotted line). The curve on the right exhibits the importance of the relative increase of the edge density in the turbulent regime.