§11. Chaos Control of Fluctuations Caused by Flute Instability in ECR Plasma

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There is an increasing interest in chaos and turbulence observed in plasmas. It is well known that turbulence causes many troublesome features in fusion oriented plasmas, that is, the instability evolves into fully developed turbulence and leads to the anomalous transport. Therefore, suppression and control of turbulence is necessary for improving the confinement. Thus, to control turbulence in plasma is one of the most important subjects in plasma physics . Although the control of turbulence is generally hard, the control of chaos will be possible. The experiments on controlling chaos have been realized in various fields, such as electronic chaos oscillator, mechanical pendulums, lasers, chemical systems and even a cardiac system. Controlling chaos in plasma has attracted much attention since controlling chaos has the advantage that it does not need high power to control. Pyragas has proposed a time-delayed feedback technique by modifying the OGY (Ott, Grebogi, and Yorke) method, which is appropriate for experimental systems working in real time. This method is based on the feedback perturbation constructed in the form of the difference between the delayed output signal and the output signal itself.

When the stabilization of unstable period is attained, this perturbation vanishes identically. Therefore, this is also a controlling method by a tiny perturbation and is a rather effective method to control a system with big power.

Here a new feedback method by modulating microwaves for ECR discharge is proposed to perform controlling chaos of fluctuations caused by the flute instability with the time-delayed auto synchronization (TDAS) method.

The experiments were performed using a large diameter ECR plasma device with an inner diameter is 400 mm and a length 1200 mm. The pressure of Ar gas is around 0.5 mTorr. The frequency of microwaves is 2.45 GHz. Microwaves are launched into a chamber as a circular TE_{11} mode thorough the waveguide uptaper and the quartz window. The plasma parameters were measured with a cylindrical single Langmuir probe. The ECR plasma parameters generated by the microwaves of 500 W are :the electron density $n_e \sim 10^{11}$ cm^{-3}, the electron temperature $T_e \sim 4$ eV and the ion temperature $T_i \sim 0.1$ eV. The experiments on controlling chaos were performed by applying a feedback signal to the microwave power source.

We examined the behavior of the ion saturation current fluctuation when the microwave was injected with CW mode. Observed fluctuation had the characteristics of the flute instability, i.e., the phase difference between density fluctuation and potential fluctuation is out of phase at the same point, the fluctuation grows at the point where the density profile has steep gradient, and the phase of the fluctuation is constant along the direction parallel to the magnetic field. The frequency of the flute instability ranged from 3 kHz to 5 kHz, depending on the gas pressure.

We calculated the correlation dimension from time series data by using the method of Grassbeger and Procaccia in order to estimate the state; periodic, chaotic or turbulent. The correlation dimension saturated to non-integer at 450 W while it did not saturate at 700 W. Therefore it is concluded that the system is chaotic and turbulent for the low microwave power and the high microwave power, respectively. We attempted controlling chaos to the present chaotic system using the TDAS, where the gas pressure and the microwave power is 0.4 mTorr and 500 W, respectively. Without feedback control, large amplitude bursts were observed. On the other hand, when TDAS feedback control was performed, such bursts disappeared, that is, the intermittency decreasesd considerably. The calculated correlation dimension of the data with TDAS became 4.0 which means that the system is periodic. Thus, we succeeded in the control of the chaos caused by the flute instability.