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Plasma confinement during the plasma relaxation stage after switching off the ECRH Pulse in the L-2M Stellarator

In recent years, a large amount of experimental data has been accumulated on the manifestations of plasma self-organization in toroidal magnetic traps, particularly on the property of plasma to maintain the profiles of some parameters under conditions of external action. The concept of plasma self-organization in toroidal magnetic traps was developed in Refs. [1–3]. It is believed that self-organization of plasma always tends to form the canonical pressure profiles in plasma, at which plasma energy loss is minimal [2, 3]. Under conditions of additional heating, the shapes of pressure profiles deviate from the canonical one. But if the additional heating is switched off, then the self-organization of plasma will result in very fast (over times of ~ 0.1 of the energy lifetime) relaxation of the pressure profiles to canonical ones. In the state with the canonical profiles of parameters, the system is stable and its energy confinement is optimal. In this case, the heat fluxes in the system are minimal.

In this work, we studied the distinctive features of plasma confinement during plasma relaxation after switching off the electron-cyclotron resonance heating (ECRH) pulse. In this stage, the plasma is not subjected to any external action of microwave radiation, and its behavior is controlled by the self-organization processes.

The experiments were performed at the L-2M stellarator. L-2M is a classical two-turn stellarator with the major radius $R = 1$ m, plasma radius $a = 0.115$ m, and magnetic field $B_0 = 1.34$ T at the axis of the plasma column [4]. ECRH was performed at the second harmonic of the

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Plasma confinement during the plasma relaxation stage after switching off the ECRH Pulse in the L-2M Stellarator

In studies of plasma confinement in L-2M during the plasma relaxation stage, we observed the effects of plasma self-organization in the dependence of the total power loss from the plasma (P_{loss}) on the plasma energy and the optimum plasma confinement available using this facility. 1

New analysis sheds light on the role of 3D stellarator fields and suppression of MHD instability activity

In axisymmetric plasmas, the equilibrium field is a source of free energy that unstable MHD modes can tap to drive instability growth. A reasonable conjecture for 3D plasmas would be that a similar role is played by the stellarator equilibrium fields. New analysis of plasmas with sawtooth oscillations on the Compact Toroidal Hybrid (CTH) device using the NIMROD code indicate that this reasonable conjecture is in fact false. Instead, the stellarator fields ($n = 5, 10, 15, \dots$) surprisingly dampen the growth of the dominant MHD modes. 4

Experimental observation of the effects of drifts on scrape-off layer flows and transport in W7-X

The effects of drifts in the scrape-off layer (SOL) can be studied by reversing the magnetic field in W7-X. Large changes in the structure of the plasma flows and asymmetries in divertor target density were observed in the experiments indicating the importance of drifts for W7-X SOL transport. 5

First announcement: 23rd Coordinated Working Group Meeting to be held June 5 – 8, 2023

The meeting will be held live in Kyoto, Japan. 6

gyrofrequency of plasma electrons (75 GHz). At the L-2M stellarator, the ECRH power can vary in the range of $P_{\text{ECRH}} = 100\text{--}1000$ kW, and the chord-averaged plasma density can be $n_e = (1\text{--}3) \cdot 10^{19} \text{ m}^{-3}$.

Figure 1 shows time evolutions of the basic plasma parameters in shot 20464 of the L-2M stellarator in the ECRH regime. The following parameters are shown from top to bottom: the plasma density $n_e(t)$ averaged along the central chord, plasma energy $W(t)$ and its derivative $dW(t)/dt$, intensity of the B II line of boron ion $I_{\text{B II}}(t)$, radiation loss power $P_{\text{rad}}(t)$, ECRH power $P_{\text{ECRH}}(t)$, and dynamic energy lifetime of plasma $\tau_E(t)$, which was defined as the ratio of the plasma energy to the total heat loss power $P_{\text{loss}}(t)$ at each time point:

$$\tau_E(t) = W(t)/P_{\text{loss}}(t). \quad (1)$$

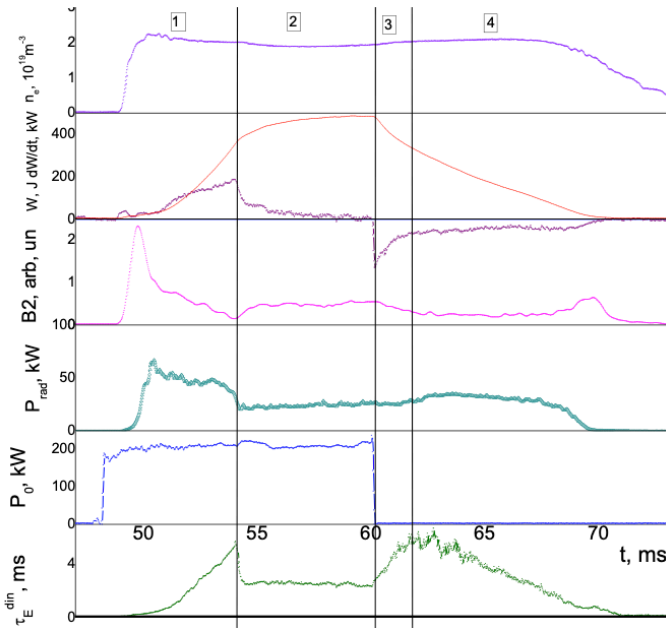


Fig. 1. Time evolutions of basic plasma parameters in shot 20464.

In this case, the loss power was determined from the global equation of energy balance using the experimental data of Fig. 1:

$$dW/dt = P_{\text{ECRH}}(t) - P_{\text{loss}}(t). \quad (2)$$

It can be seen in Fig. 1 that, during the shot, four phases can be distinguished in the plasma confinement (in the figure, the phases are marked by numbers, and the times of transitions between the phases are shown by vertical lines) [5, 6]. The successive change of confinement phases is especially clearly visible in the $\tau_E(t)$ dependence.

In the phase of plasma relaxation after switching off the

ECRH pulse, that is, in phase 3 (Fig. 1), the total power loss of plasma as a function of plasma energy $P_{\text{loss}}(W)$ was measured at different plasma densities. These experimental data are well approximated by the following function:

$$P_{\text{loss}}(W, n_e) = P_0 \times (W/W_0)^\alpha (n_e/n_0)^{-\beta}, \quad (3)$$

where $\alpha \approx 3.1$ and $\beta \approx 2.2$.

We emphasize once again that in the relaxation phase, the confinement of plasma energy is determined by the self-organization processes. Therefore, in accordance with the concept of plasma self-organization, in formula (3), $P_{\text{loss}}(W, n_e)$ is the minimum loss power for each of the plasma energies.

Using the experimental dependence $P_{\text{loss}}(W, n_e)$, a scaling law was obtained for the L-2M relaxation phase:

$$\tau_{\text{Edecay}}^{\text{L-2M}} = 2.47 \times 10^{-3} n_e^{0.715} P_{\text{loss}}^{-0.675}, \quad (4)$$

where τ_E is measured in seconds, n_e is in units of 10^{20} m^{-3} , and the loss power P_{loss} is in megawatts.

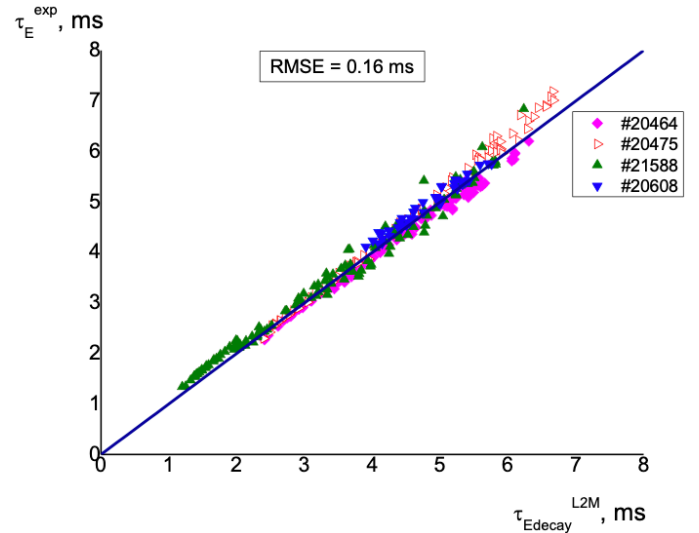


Fig. 2. Experimental energy lifetime in phase 3 vs energy lifetime in phase 3 calculated using scaling law (3) for the L-2M stellarator.

In Fig. 2, the vertical axis corresponds to the dynamic energy lifetime τ_E^{exp} in the relaxation phase calculated using the experimental data, and the horizontal axis shows the energy lifetime determined using formula (3). Figure 2 shows that in phase 3, the experimental energy lifetimes are in good agreement with scaling law (4).

Scaling law (4) is close to the single-machine scaling law obtained previously for the quasi-stationary stage (phase 2) of the L-2M shots [7]:

$$\tau_E^{L-2M} = 2.32 \cdot 10^3 n_e^{0.714} P_{\text{loss}}^{0.695}, \quad (5)$$

where τ_E is measured in seconds, n_e is in units of 10^{20} m^{-3} , and the loss power P_{loss} is in megawatts. This is not an accidental coincidence. Scaling law (4) results from plasma self-organization processes under the conditions of the relaxation phase. It determines the best possible conditions for plasma confinement in the L-2M stellarator and is the “upper bound” for scaling law (5) obtained for the quasi-stationary phase. In the quasi-stationary phase of plasma confinement, in addition to the minimum losses P_{loss} , additional losses result from small deviations of the pressure profile from the canonical profile. The confinement conditions somewhat worsen, but not too much, as confirmed by the similarity of scaling laws (4) and (5).

Thus, we can see that, at the L-2M stellarator, in the quasi-stationary and relaxation phases, the plasma confinement and scaling laws are determined by the processes of plasma self-organization.

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New analysis sheds light on the role of 3D stellarator fields and suppression of MHD instability activity

It is a well-known result in toroidal fusion plasma physics that as more of the rotational transform for plasma confinement comes from external stellarator coils magnetohydrodynamic (MHD) instabilities are suppressed. An important, fundamental question for these three-dimensional (3D) plasmas is the role played by the equilibrium stellarator magnetic fields in relation to the unstable MHD modes of the system. In axisymmetric plasmas, the equilibrium field is a source of free energy that unstable MHD modes can tap to drive instability growth. A reasonable conjecture for 3D plasmas would be that a similar role is played by the stellarator equilibrium fields, i.e., these fields are also a source of free energy to drive instabilities. Understanding the role of the stellarator fields and the suppression of MHD modes is an important goal in furthering our knowledge of these 3D plasmas.

New analysis of plasmas with sawtooth oscillations [1,2] in the Compact Toroidal Hybrid (CTH) device using the NIMROD code indicate that this reasonable conjecture is in fact false. Instead, the stellarator fields ($n = 5, 10, 15, \dots$) surprisingly damp the growth of the dominant MHD modes. The free energy source for driving MHD instability in these 3D plasmas remains the axisymmetric equilibrium field ($n = 0$), see Fig. 1.

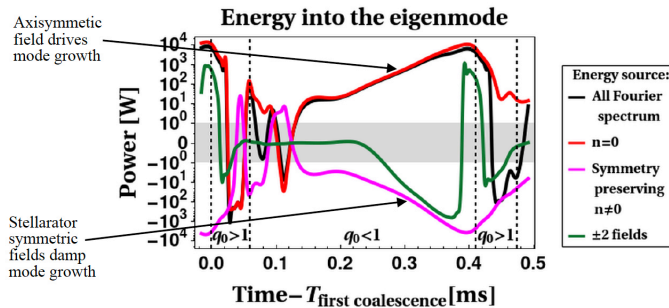


Fig. 1. Power transfer into the kink eigenmode from the whole Fourier spectrum, the $n = 0$ field, the stellarator symmetry preserving fields ($n = 5, 10, 15, \dots$), and sideband fields showing kink mode growth is driven by the $n = 0$ axisymmetric field. The power scale is linear within the gray area and logarithmic elsewhere.

We conjecture that this damping mechanism, which takes energy out of the MHD mode, is generic and possibly responsible for the stabilization of MHD activity as increasing levels of external stellarator field are added to CTH dis-

charges as well as in other stellarator experiments. Future computations and experiments on CTH will address and inform the validity of this conjecture.

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Experimental observation of the effects of drifts on scrape-off layer flows and transport in W7-X

Drifts affect particle, momentum, and energy transport in the scrape-off layer (SOL) of both tokamaks and stellarators, altering plasma flows and creating asymmetries between inboard and outboard divertor plates that can change and possibly hamper divertor operation and performance. Hence understanding the effects of drifts on the SOL is important. These drift effects can be even more pronounced in stellarator plasmas due to their 3D SOL structure. To understand how important drifts are to SOL transport in the Wendelstein 7-X (W7-X) island divertor, flow measurements have been made with coherence imaging spectroscopy (CIS) in experiments able to reverse the direction of the magnetic field, thus reversing the particle drifts and hence changing the drift-induced transport. Large changes in the structure of the plasma flows and asymmetries in divertor target density were observed in the experiments, indicating the importance of drifts for W7-X SOL transport.

At low density, it was found that the $\mathbf{E} \times \mathbf{B}$ drift induces a large poloidal density asymmetry within the island SOL. This in turn causes substantial changes to the plasma flow as measured by CIS, making it near-unidirectional throughout the entire SOL as shown in Fig. 1 (a) and (b). As the density was increased, the effects of the $\mathbf{E} \times \mathbf{B}$ drift decreased substantially, resulting in a smaller density asymmetry and the development of a counter-streaming flow pattern, as seen in Fig. 1 (c) and (d). Future experiments aim to address the important question of how these drifts affect divertor target heat loads during operation of the High Heat Flux (HHF) divertor in OP 2 operation.

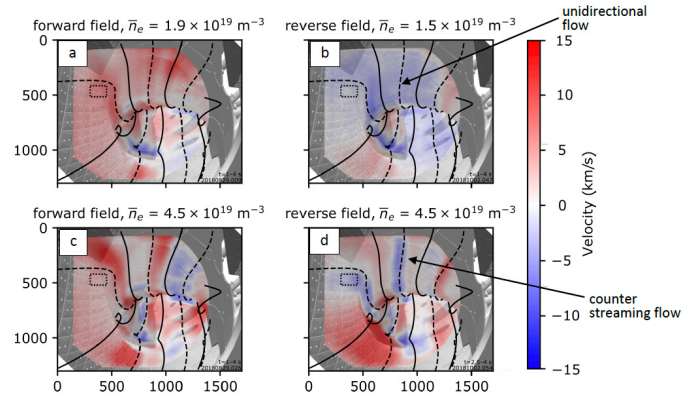


Fig. 1. Effect of magnetic field reversal on C²⁺ impurity flow measured by CIS in low-density (a, b) and high-density (c, d) plasmas. The trajectories of the island O-points (X-points) are over-plotted as solid (dashed) black lines. Clear reversal of the flow patterns is observed in forward and reverse field experiments, indicating that the flows are strongly influenced by the drift motion.

D. M. Kriete, D. A. Ennis, D. A. Maurer, J. C. Schmitt
Auburn University

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First announcement: 23rd Coordinated Working Group Meeting to be held June 5–8, 2023

Dear Colleagues,

We are pleased to announce that the 23rd Coordinated Working Group Meeting (CWGM) of the Stellarator-Heliotron Technology Collaboration Programme (SH-TCP) under the auspices of the International Energy Agency will be held June 5–8, 2023, in Kyoto, Japan.

The CWGM is a working meeting, not a scientific conference. The CWGM fosters and promotes international collaborations within the stellarator-heliotron community and synergies with tokamaks and other magnetic field configurations. The meeting outcome will be agreed joint actions and recommended joint experiments for the members of the SH-TCP.

The program will cover strategic discussions for task forces, joint actions, tokamak/stellarator cooperation, and future directions for the stellarator-type reactor. Please get in touch with the following colleagues if you intend to contribute to the following topics:

Core transport and confinement in multi-ion plasmas

- M. Nunami (NIFS), D. Carralero (CIEMAT)

Energy, particle, and impurity transport in the SOL and divertor

- A. Bader (UWM), V. Winters (IPP)

Energetic Particles, MHD, and High Beta

- A. Knieps (FZJ), A. Wright (PPPL)

On-site attendance is strongly encouraged and will be limited to about 50 persons. Remote participation will be offered. Further information will be announced in the second announcement. Please feel free to contact Yasuhiro Suzuki (suzukiy@hiroshima-u.ac.jp) or Kazunobu Nagasaki (nagasaki.kazunobu.4x@kyoto-u.ac.jp) for any organizational issues.

We are looking forward to seeing you in Kyoto!

Sincerely,

The CWGM Organizing Committee:

Yasuhiro Suzuki (Hiroshima University, Japan)

Naoki Tamura (NIFS, Japan)

Arturo Alonso (CIEMAT, Spain)

Dorothea Gradic (IPP, Germany)

Benedikt Geiger (UW Madison, USA)

Novimir Pablant (PPPL, USA)