

Effect of induced sheared rotation on plasma stability during strong ECRH in the GDT magnetic mirror device

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Introduction

Electron cyclotron resonance heating (ECRH) technique has proven effective at increasing bulk electron temperature (T_e) of plasma in an axisymmetric magnetic mirror device GDT, allowing the values up to 0.9 keV to be achieved [1] in a discharge sustained by combined ECRH and neutral beam injection (NBI) heating. However, it has been repeatedly observed that highly localized power deposition of ECRH is able to affect the MHD stability of plasma confined in a mirror machine [1, 2], leading to increased transverse transport during the additional heating. In previous experiments at GDT [1, 3] it was found that ECRH power can focus in a near-axial region due to doppler-broadening of EC resonance and oblique propagation of microwave beam. As a consequence, a narrow radial distribution of T_e is established with high on-axis temperature values, which are maintained long enough to reach longitudinal heat flux equilibrium. After ~ 0.6 ms the profile is destroyed by MHD instability, which rapidly grows and leads to increased transverse losses of plasma and eventual violation of ECR heating conditions. The goal of reported experiments was to find a way to overcome the instability and to show that if additional measures are taken to stabilize plasma during ECRH, highly peaked temperature profile can be sustained for the whole duration of plasma heating without any significant impact on plasma stability. After that, steady ECR heating conditions would allow for a thorough check of both longitudinal and transverse energy transport models in axisymmetric open-ended magnetic confinement systems, verification of which is crucial for the advanced concepts of fusion devices based on magnetic mirror machines [4]. The paper introduces the basic idea for plasma stabilization and presents the essential experimental results.

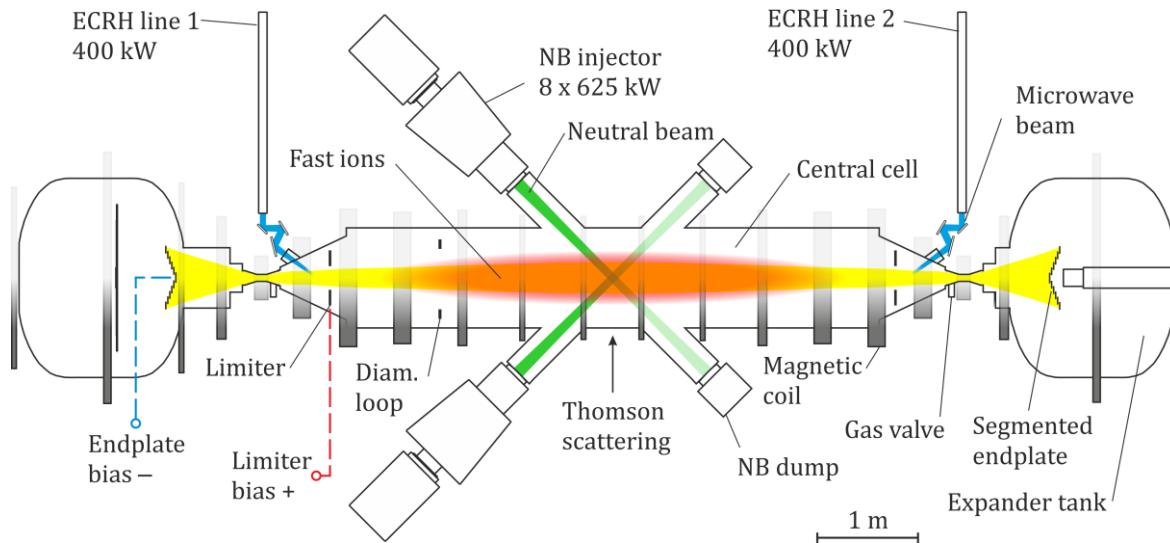


Fig.1. GDT layout. Two compact 12-ring endplates were installed at both ends of the machine.

GDT setup

Detailed description of GDT and its current experimental goals is given in [5]. The idea of how to locally influence the core region of plasma is directly related to the main plasma stabilization technique developed for the GDT experiment – the vortex confinement [6], which employs radial limiters (fig.1) to induce differential $E \times B$ rotation at plasma border. Similarly, a potential jump should be placed in a region with high temperature gradient produced by ECRH. To facilitate this, two radially segmented endplates (fig.1) were installed at both ends of the machine to propagate an externally shaped potential distribution into plasma. As the endplates are not compatible with arc plasma generator, the experiment relies on ECR breakdown [7] to supply initial plasma target for NBI, limiting total ECRH power at the developed stage of the discharge to 400 kW.

Experimental results

Fig. 2 shows the experimental scenario and typical diamagnetic signals of fast ions in discharges with 400kW ECR heating. As it was observed previously, application of ECRH leads to plasma decay (curve (a)) after ~ 0.6 ms of microwave heating and corresponding growth of stray radiation signal, indicating a switch to poor microwave absorption (fig.2, bottom). However, if a negative bias of at least ~ 400 V is applied to the core region of plasma, the instability does not develop for the whole duration of microwave pulse and high attenuation of microwave power is maintained. Very low amplitude of low frequency (~ 10 kHz) plasma oscillations is observed by a set of B-dot probes around the fast ion

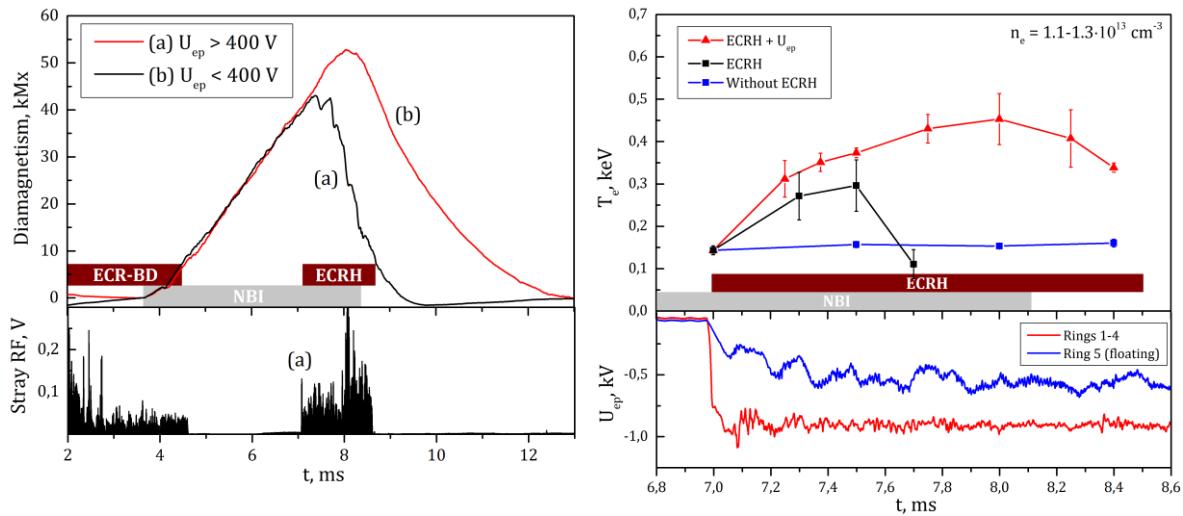


Fig. 2. Left: diamagnetic signals of plasma with and without additional endplate bias (top), corresponding stray microwave signals (bottom). Right: time dependencies of electron temperature (top), endplate potential (bottom).

reflection point. Typical radial distribution of endplate bias (projected to midplane) is shown in bottom part of fig. 3. Plasma stabilization occurs in case of 3, 4 and 5 biased discs projecting to diameters of 7.2, 9.5 and 11.8 cm at midplane. The width of optimal (with regards to maximum T_e) potential profile roughly corresponds to that of the temperature profiles measured both previously [3] and during this experiment (fig. 3).

The time dependence of electron temperature (fig. 2, right) at the axis was measured by Thomson scattering diagnostic over a series of discharges with identical conditions. In contrast to previous experiments, which registered temperature falloff with the onset of instability, in this case high T_e values are observed during the whole ECRH pulse. Much improved shot-to-shot repeatability of T_e values together with B-dot probe data indicate that steady ECR heating conditions are realized. There is evidence that the particular time dependence of T_e shown in fig. 2 is now determined by variation of magnetic field during ECRH pulse – ray tracing simulations predict that the specific power absorbed in the axial region of plasma is extremely sensitive to magnetic field strength in ECR zone, requiring magnetic field stability better than 1%. Preliminary data suggests that after the stabilization is achieved at $U_{ep} \sim 400$ V, the saturated level of electron temperature does not depend on external bias.

Conclusions

In previous experiments on ECR plasma heating in GDT it was found that due to peculiar geometry the microwave power in some cases tends to focus in a near-axial plasma region,

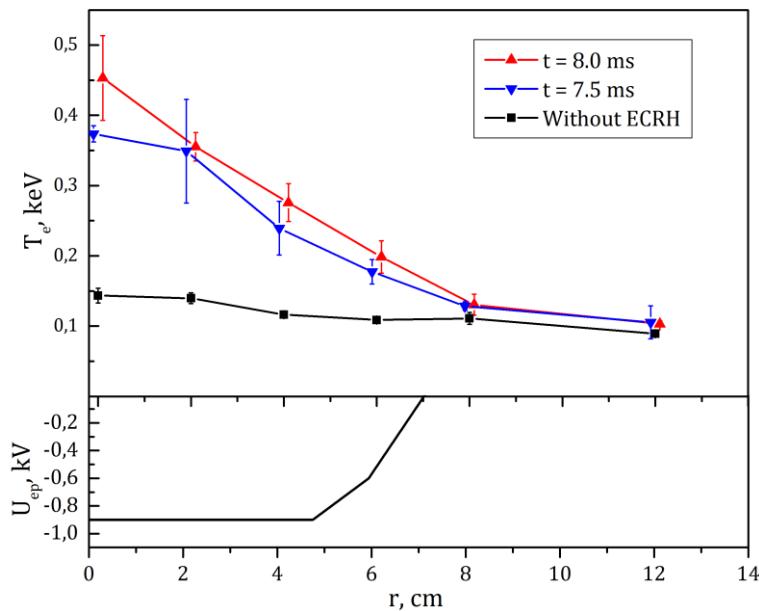


Fig. 3. Radial profiles of T_e in stable ECRH regime (top). Applied potential distribution (bottom).

leading to multifold increase of electron temperature, but also giving rise to flute instability. The latter restricted the period of efficient microwave heating to $\sim 0.6\text{ ms}$ and often led to complete loss of plasma.

It is observed that a flat negative bias locally applied to a region with the strongest microwave absorption suppresses large scale MHD oscillations. Moreover, it is shown that a highly peaked radial profile of electron temperature with $\nabla T_e > 4 \text{ keV/m}$ can be sustained as long as ECRH and NBI are applied. Note that in these experiments a special case of ECR heating in GDT is investigated with an aim of laying an experimental basis for a comprehensive transport study in axisymmetric linear machines. In general case, a more widespread deposition of microwave power can be realized [3], with strong impact on fast ion confinement time and no stability issues.

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