Plasma potential and geodesic acoustic mode evolution with Helium puffing in the ECRH regime on the T-10 tokamak

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Abstract. The evolution of the Geodesic Acoustic Mode (GAM) and mean plasma electric potential were examined in the regime with short (5 ms) Helium puffing into Electron Cyclotron Resonance heated discharge of the T-10 tokamak. It was shown that a Helium pulse leads to temporal perturbation of the plasma electron temperature and density and concomitant evolution of the mean potential, happening in the diffusive time-scale \(\sim 30\) ms. Afterwards, the potential restores to the new stationary level with the same time-scale. On top of that GAM amplitude reduces sharply (within 2-5 ms) and GAM frequency also decreases within 30 ms after Helium puffing. Afterwards GAM amplitude and frequency relax to a new stationary level within about 50-70 ms. The evolution of electron density, electron and ion temperatures, total stored energy and plasma density turbulence is discussed in order to clarify their links with potential and GAM evolution.

1. Introduction
Physical mechanisms of the turbulent energy transport present an open area in fusion research. One of the important phenomena in this field are Zonal Flows and their high-frequency counterpart GAMs. They have been intensively studied as a possible mechanism of the plasma turbulence self-regulation [1]. They were first introduced in [2] within the ideal Magneto Hydro Dynamic (MHD) model. GAM is a perturbation with \(m = n = 0\) for electrostatic potential, which is coupled to pressure perturbation \(m = 1, n = 0\). GAM frequency is proportional to the square root of temperature [2]. The main features of GAM on T-10 were described in [3]. The recent observations show that periphery plasma parameters play important role in the GAM behavior [4]. Besides, the mean electric field (or potential) plays a role in plasma confinement and turbulent transport [5]. This paper presents the evolution of the GAM and mean electric potential induced by the perturbation of the periphery due to the Helium puffing into Electron Cyclotron Resonance Heated (ECRH) plasmas.

2. Experimental setup
T-10 is a circular tokamak (major radius \(R = 1.5\) m, minor radius \(a = 0.3\) m, \(B < 2.5\) T) with a rail carbon limiter. Plasma potential oscillations in the hot plasma were studied with Heavy Ion Beam Probe (HIBP), a unique method of the direct measurement of plasma electric potential. The basic principles of HIBP were described in [6], while the T-10 HIBP with TI\textsuperscript{+} probing beam was described in [5, 7].

Discharge scenario and the evolution of the main plasma parameters are presented in figure 1.

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Figure 1. Scenario of the discharge with He puffing and the evolution of the main plasma parameters. Here \( \bar{n}_e \) - central chord line-averaged plasma density, \( T_e (r/a = 0.64) \) electron temperature, and \( T_i (r/a = 0.80) \) ion temperature, \( W_{\text{dia}} \) – total stored energy.

The high density \( \bar{n}_e = (3.5-4.5) \times 10^{19} \text{ m}^{-3} \) ohmic plasma is auxiliary heated by Electron Cyclotron Resonance Heating (ECRH) from 600 to 950 ms. A short pulse (~5 ms) of He puffing is performed at 700 ms. After puffing the central chord line-averaged plasma density, measured by microwave interferometer stops the decay due to the pump-out and starts to raise. On top of that both \( T_e \), retrieved from the database of the Electron Cyclotron Emission, and \( T_i \) measured by CHERS [8] decreases for about 25 ms, then relax to a new steady state level, which appear to be somewhat lower than the initial one before He pulse. At this new steady state the electron density rises up by about 15% with respect to the initial level. After He pulse the energy content (\( W_{\text{dia}} \), as measured by diamagnetic loop) decreases for about 25 ms due to the temperature decrease then reaches a new steady state. New level of energy content is higher by ~ 10% than the level before puffing due to the density increase.

3. Experimental results

3.1. Evolution of the GAM properties due to the Helium pulse.

The fine details of the main plasma parameters and GAM evolution, as measured in the plasma periphery \( r = 19 - 30 \text{ cm} \) are presented in figure 2. Fourier spectrogram of potential oscillations, measured by HIBP is shown in figure 2 (a). GAM is clearly seen as a dominating frequency peak, evolving in time with the ECRH and Helium pulse. GAM amplitude, which is calculated over the wide frequency region (5-25 kHz), with a pronounced peak indicated by dark grey color in figure 2 (a), is shown in figure 2 (b). Right after the Helium pulse GAM amplitude abruptly falls down from 25 V almost to the noise level during 2-5 ms. GAM amplitude reaches minimum values and then evolves slowly to the new steady-state with a characteristic time of about 70 ms, which is close to the density and temperature relaxation time. The time trace of the GAM frequency or the mean frequency of the pronounced GAM peak is shown in figure 2 (c). The GAM frequency increases from its ohmic level of \( \sim 12 \text{ kHz} \) to its ECRH level \( \sim 17 \text{ kHz} \) according to the \( T_e \) raise due to the ECRH. Then it decreases
from ~ 17 kHz down to ~12-13 kHz during ~ 25 ms after the Helium pulse, which is in a sharp
contrast to the dynamics of the GAM amplitude.

![Figure 2](image)

Figure 2. (a) —
power spectrogram
(power spectral
density, psd) of
potential oscillations,
measured by HIBP at
r = 26 cm, (b) —
GAM amplitude, (c)
— GAM frequency,
(d) — electron
density, measured by
microwave interferometry at the
downstroke chord, (e) —
electron temperature,
retrieved from the
database of the
Electron Cyclotron
Emission, (f) — ion
temperature,
measured by CHERS,
(g) — density
turbulence level,
measured by
Correlation Reflectometry. Both
(f) and (g) were
averaged over the
series of identical
shots (#65488
—
65492). Solid vertical
line indicates Helium
puffing, dash line minimum of the
GAM frequency,
coinciding with a
minimum of T_e, dot line — the steady
state for GAM
class.

After reaching the minimum value GAM frequency increases to the new steady-state. It relaxes to
this new steady state during about 50 ms, mainly in line with evolution of T_e and T_i. Other plasma
parameters also evolve after the impurity pulse. Figure 2 (d) shows the time-trace of the local (edge)
density, measured by the outermost chord of the microwave interferometer. Figure 2 (e) presents
electron temperature, derived from the T-10 database measured by Electron Cyclotron Emission
according to [9], while figure 2 (f) is for the ion temperatures measured by Charge Exchange
Recombination Spectroscopy [8]. Figure 2 (g) shows the evolution of the broadband turbulence level obtained by Correlation Reflectometry.

3.2. **Evolution of the mean potential due to the Helium pulse**

In the high-density regime under study the mean potential level has negative absolute values all over the radius [5, 10]. The fine details of the global plasma parameters and mean potential evolution are shown in figure 3. The time evolution of the line-averaged density, measured by the central chord of microwave interferometer is shown in figure 3 (a), while the energy content, measured by diamagnetic signal is shown in figure 3 (b). After ECRH switch-on the absolute value of plasma potential decreases in consistency with earlier observations [10]. Contrary, after the Helium pulse its absolute value increases. This increase lasts much longer than Helium pulse (5 ms) and takes about diffusion time (~25-30 ms).

**Figure 3.** Evolution of electron density (a), diamagnetic energy (b) and plasma potential (c), grey shade represents experimental errors.

Afterwards mean potential starts to recover, the absolute value of its average level falls during 30-35 ms. Then the potential reaches a new quasi steady-state level for t=800-900 ms. This new level of absolute potential appears to be slightly higher than the initial stationary level before Helium puffing t=630-670 ms, which is consistent with the general link between mean potential and stored plasma energy [5]. Note that the minimum of energy content coincides in time with change in sign of the density time derivative. The time instant of potential minimum at the periphery is delays with respect to the minimum of total stored plasma energy by about 10 ms, which can be caused by the transient processes in the bulk plasma particle transport or Helium distribution over the plasma column.
4. Summary
Helium puffing dramatically changes the GAM behavior: GAM frequency decrease temporarily after the He pulse. GAM frequency evolution is consistent with the evolution of $T_e$ and $T_i$ at the plasma periphery. Unlike GAM frequency GAM amplitude reacts on Helium pulse abruptly (2-5 ms). Such sharp decrease can be probably linked with global character of GAM [11]. The further increase of GAM amplitude is consistent with collisional damping, caused by edge density evolution. On top of that Helium pulse affects the mean plasma potential. Potential evolution mainly follows the density one and reveals its links with energy content.

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