STUDY OF POLOIDAL STRUCTURE OF GEODESIC ACOUSTIC MODES IN THE T-10 TOKAMAK WITH HEAVY ION BEAM PROBING

V.N. Zenin[1], L.G. Eliseev[1], A.S. Kozachek[2], L.I. Krupnik[2], S.E. Lysenko[1], A.V. Melnikov[1, 3], S.V. Perfilov[1]

[1] Institute of Tokamak Physics, NRC ''Kurchatov Institute'', 123182, Moscow, Russia;
[2] Institute of Plasma Physics NSC “Kharkov Institute of Physics and Technology”, Kharkov, Ukraine;
[3] National Research Nuclear University MEPhI, Moscow, Russia

E-mail: vitalyzenin@mail.ru

The poloidal structure of geodesic acoustic modes (GAMs) was studied on the T-10 tokamak by heavy ion beam probing with multichannel energy analyzer. GAMs were mainly pronounced on the plasma electric potential. The poloidal phase shift between the potential oscillations was determined by the two-point correlation technique. It was shown that GAM potential oscillations have the poloidal mode number m=0 in the core plasma. This experimental result agrees with theoretical predictions.

PACS: 52.35.Mw, 52.35.Ra, 52.55.Fa

INTRODUCTION

Geodesic acoustic modes (GAMs) are the high-frequency branch of zonal flows in toroidal fusion devices. GAMs are actively studied in tokamaks and stellarators as one of possible mechanisms of the plasma turbulence self-regulation by the oscillating radial electric field [1]. GAMs should transform the radial turbulent oscillations, which outflow the energy from plasma, into the torsional plasma oscillations, which do not transfer the energy radially. Therefore, a linear theory predicts that the poloidal mode number for GAM potential oscillations is m=0 [2]. However, this prediction was not yet validated experimentally in the core plasma. The presented report contains such validation.

1. EXPERIMENTAL SETUP

The GAM oscillations are systematically studied at the circular tokamak T-10 (R=1.5 m, a=0.3 m, B=1.5…2.5 T, I_{pl}=0.15…0.3 MA) using heavy ion beam probing (HIBP) [3, 4]. HIBP is a direct diagnostic for studying the electric potential φ and its oscillations, on which GAMs are very clearly seen. This diagnostic is especially convenient for study the GAM characteristics in the plasma core, which is inaccessible for Langmuir probes usually investigating GAMs at the plasma edge [5]. Principles of HIBP measurements of potential in T-10 were described in [6]. In T-10 we used the ions Tl^+ with energy up to E_b<280 keV, provided the spatial and temporal resolution < 1 cm, <10 μs correspondingly. Varying the beam energy and injection angle, we can form the detector grid containing the observation points (sample volumes). For registration we used the energy analyzer with five slits (Fig. 1). It provided the spatial and temporal resolution < 1 cm, <10 μs correspondingly at the radial range 6 < r < 30 cm for B=1.5 T [7]. This new analyzer allows us to carry out simultaneous measurements in several neighboring sample volumes. The magnetic flux surfaces in poloidal cross-section of T-10 are circular. Therefore we can choose sample volumes at very near flux surfaces that allow us to estimate the poloidal mode number m for GAMs, which we seen on the potential oscillations (Fig. 2). Relation between phase shift and poloidal mode number m can be derived by the method of two-point correlations, used in HIBP experiments in the TJ-II stellarator [8]. With this method the poloidal mode number was detected for electromagnetic modes like Helical Alfvén Eigenmodes [9, 10] and also for electrostatic modes like Supra Thermal Electron induced modes in complex bean-shape geometry of TJ-II plasmas [11].

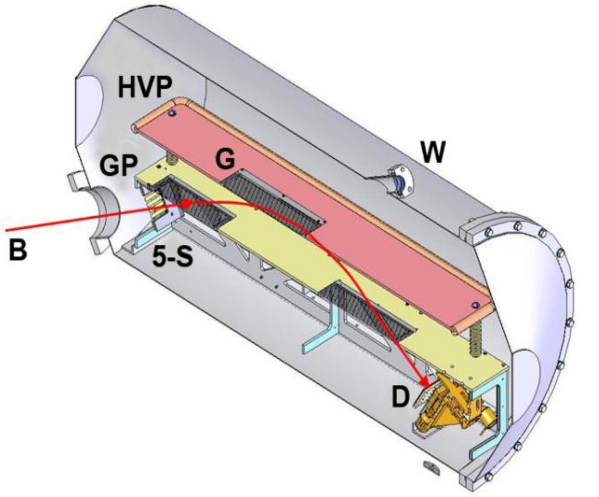

Fig. 1. The five-slit energy analyzer. B – beam; D – detectors; G – grid; GP – ground plate; HVP – high-voltage plate; W – window; 5-S – entrance slits

Taking into account the simple circular geometry of T-10, this method may be simplified as follows. If m=1, then the phase shift along the whole flux surface, which presents the circumference with a length $2\pi r$ in the poloidal plane, is equal to 2π. For arbitrary m this phase shift will be $2\pi m$. As the shift is measured over a small part of the circumference s, it should be smaller in proportion of distance between the points on magnetic

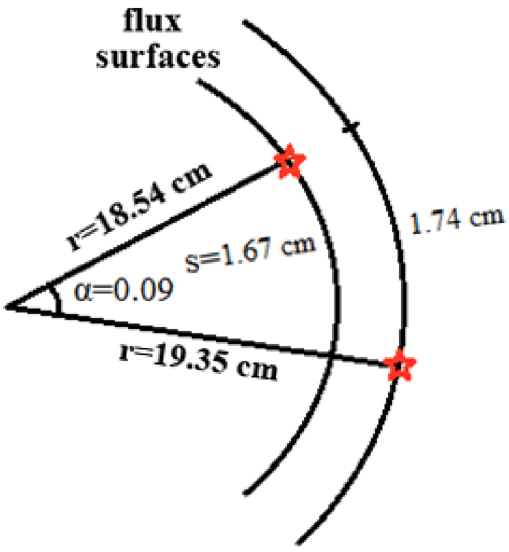

Fig. 2. Relation between the phase shift and poloidal mode number m, shot №62742, sample volumes (stars) on middle radii. B=2.4 T, E_b=280 keV

surface to the whole length of circumference. So, for the phase shift $\Theta_{\varphi1\varphi2}$ we obtain:

$$\Theta_{\varphi_1\varphi_2} = m\frac{s}{r}\,. \tag{1}$$

Using circular symmetry of T-10, we can replace the relation *s/r* by more universal value of the angle α between the points of measurement and the plasma centre (see Fig. 2). Finally we obtain:

$$\Theta_{\varphi_1\varphi_2} = m\alpha\,. \tag{2}$$

2. EXPERIMENTAL RESULTS

Data from different sample points are processed simultaneously; therefore we can perform the spatial correlation measurements. To obtain information about oscillations, we performed the spectral analysis of HIBP data. This allows us to transform the temporal variation of signal into its frequency components using the fast Fourier transformation. To determine the poloidal structure of GAM we used the signals of potential measured by the central slit of analyzer φ_3 and by the edge slit φ_5. We define the power spectral density (PSD), coherency and phase shift $\Theta_{\varphi1\varphi2}$. The results of analysis for shot № 62818 together with time traces of discharge current I_{pl} and line-averaged density $\bar{n}_e$ are shown in Fig. 3.

Signals from both slits are very similar. We see the main peak and high-frequency satellite with frequencies about 20 kHz. They have rather good coherency, coh>0.8, and their cross-phase is near zero. This means that *m*=0.

The similar results were obtained for another slits and for different discharges. Fig. 4 presents the phase for intermediate slits number 2 and 4 in discharge with rising density. We see that again *m*=0.

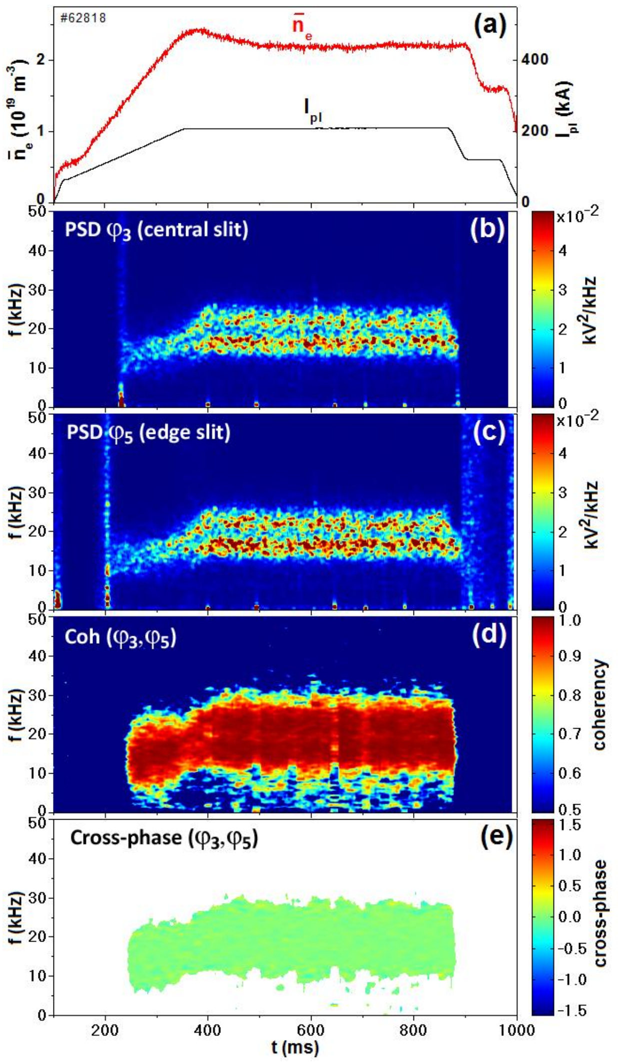

Fig. 3. Traces of plasma current I_{pl} and density n_e (a); power spectral densities of potential oscillations measured by central slit φ_3 and by edge slit φ_5 (b) and (c) at radius r=17 cm, B=2.28 T, their coherency (d) and cross-phase (e)

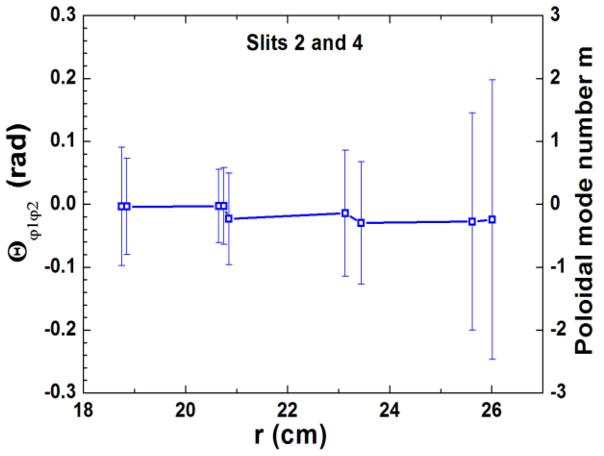

Fig. 4. The phase shift between the potential oscillations and the poloidal mode number m measured by intermediate slits of analyzer. Discharge parameters B = 2.3 T, n_e = (0.9...2.4)×10^{19} m^{-3}, I_{pl} = 220 kA ohmic heating

SUMMARY

The multichannel energy analyzer makes heavy ion beam probing an effective tool to study the poloidal structure of geodesic acoustic modes with two-point correlation technique. It was shown that GAM associated potential oscillations are poloidally uniform, so GAM has the poloidal mode number *m*=0 in potential of the core plasma. This experimental result agrees with theoretical predictions [2].

ACKNOWLEDGEMENTS

The research is carried out by financial support of Russian Scientific Foundation project 14-22-00193.

REFERENCES

1. A. Fujisawa et al. Experimental progress on zonal flow physics in toroidal plasmas // *Nucl. Fusion*. 2007, v. 47, p. S718.
2. P.H Diamond et al. Zonal flows in plasma – a review // *Plasma Phys. Control. Fusion*. 2005, v. 47, p. R35.
3. A.V. Melnikov et al. Investigation of geodesic acoustic modes oscillations in the T-10 tokamak // *Plasma Phys. Control. Fusion*. 2006, v. 48, p. S87.
4. A.V. Melnikov et al. Investigation of the plasma potential oscillations in the range of geodesic acoustic mode frequencies by heavy ion beam probing in tokamaks // *Czech. J. Phys*. 2005, v. 55, p. 349.
5. W. Chen et al. Observation of energetic-particle-induced GAM and nonlinear interactions between EGAM, BAEs and tearing modes on the HL-2A tokamak // *Nucl. Fusion*. 2013, v. 53, p. 113010.
6. A.V. Melnikov et al. Electric potential dynamics in OH and ECRH plasmas in the T-10 tokamak // *Nucl. Fusion*. 2013, v. 53, p. 093019.
7. A.V. Melnikov et al. HIBP diagnostics on T-10 // *Review of scientific instruments*. 1995, v. 66, p. 317.
8. L.G. Eliseev et al. Two Point Correlation Technique for the Measurements of Poloidal Plasma Rotation by Heavy Ion Beam Probe // *Plasma Fusion Research*. 2012, v. 7, p. 2402064.
9. A.V. Melnikov et al. Internal measurements of Alfvén eigenmodes with heavy ion beam probing in toroidal plasmas // *Nucl. Fusion*. 2010, v. 50, p. 084023.
10. A.V. Melnikov et al. Alfvén Eigenmodes properties and dynamics in the TJ-II stellarator // *Nucl. Fusion*. 2012, v. 52, p. 123004.
11. A.V. Melnikov et al. A Quasi-Coherent Electrostatic Mode in ECRH Plasmas on TJ-II // *Plasma Fusion Research*. 2011, v. 6, p. 2402030.

Article received 23.10.2014

ИССЛЕДОВАНИЕ ПОЛОИДАЛЬНОЙ СТРУКТУРЫ ГЕОДЕЗИЧЕСКИХ АКУСТИЧЕСКИХ МОД В ТОКАМАКЕ Т-10 С ПОМОЩЬЮ ПУЧКА ТЯЖЕЛЫХ ИОНОВ

В.Н. Зенин, Л.Г. Елисеев, А.С. Козачек, Л.И. Крупник, С.Е. Лысенко, А.В. Мельников, С.В. Перфилов

На токамаке Т-10 с помощью пучка тяжелых ионов исследована полоидальная структура геодезических акустических мод (ГАМ), которые явно видны на потенциале плазмы. Фазовый сдвиг между колебаниями потенциала определялся методом двухточечной корреляции с помощью многоканального энергетического анализатора. Показано, что ГАМ на потенциале имеют полоидальное модовое число *m*=0. Этот экспериментальный результат согласуется с теоретическими предсказаниями.

ДОСЛІДЖЕННЯ ПОЛОЇДАЛЬНОЇ СТРУКТУРИ ГЕОДЕЗИЧНИХ АКУСТИЧНИХ МОД У ТОКАМАЦІ Т-10 ЗА ДОПОМОГОЮ ПУЧКА ВАЖКИХ ІОНІВ

В.Н. Зенін, Л.Г. Єлісєєв, О.С. Козачок, Л.І. Крупник, С.Є. Лисенко, О.В. Мельников, С.В. Перфілов

На токамаці Т-10 за допомогою пучка важких іонів досліджена полоїдальна структура геодезичних акустичних мод (ГАМ), що явно видно на потенціалі плазми. Фазове зміщення між коливаннями потенціалу визначається методом двохточечної кореляції за допомогою багатоканального енергетичного аналізатора. Показано, що ГАМ на потенціалі мають полоїдальное модове число *m*=0. Цей експериментальний результат узгоджується з теоретичними передбаченнями.