PLASMA POTENTIAL CORRELATIONS BETWEEN HEAVY ION BEAM PROBE AND LANGMUIR PROBE ON THE T-10 TOKAMAK

V.N. Zenin[1], M.A. Drabinskij[1], L.G. Eliseev[1], S.A. Grashin[1], P.O. Khabanov[1], N.K. Kharchev[1], L.I. Krupnik[2], A.V. Melnikov[1,3]

[1]NRC Kurchatov Institute, Moscow, Russia;
[2]National Science Center "Kharkov Institute of Physics and Technology",
Institute of Plasma Physics, Kharkiv, Ukraine;
[3]National Research Nuclear University MEPhI, Moscow, Russia

This work is dedicated to simultaneous measurements of plasma potential oscillations at GAM frequencies in different locations on the T-10 tokamak and studying their correlation properties. Recent experiments with Heavy Ion Beam Probing and Langmuir probes have shown high coherency between signals of two diagnostics (up to 0.8) despite a large distance between the observation points: half of torus in toroidal and about π in poloidal direction, up to 12 cm in radial direction. The phase shift between potentials measured with two diagnostics has been obtained in two plasma scenarios. It was found the most likely that potential oscillations at the GAM frequency propagate outward, but influence of 2π phase shift cannot be excluded.

PACS: 52.55.Fa, 52.35.Fp, 52.70.-m

INTRODUCTION

In the recent years there has been significant interest to Geodesic Acoustic Modes (GAMs). GAMs, being the high-frequency counterpart of zonal flows, can be generated by turbulence and regulate the turbulence in return. It has been shown theoretically that GAMs manifest themselves as oscillations of plasma electric potential with $m = n = 0$ (and can weakly be seen on density with $m = 1$, $n = 0$) [1, 2]. Present paper shows the evidence of the long-range radial coherence for GAM.

1. EXPERIMENTAL SETUP

GAMs have been studied with two diagnostics: Langmuir probes (LP) [3] and Heavy Ion Beam Probing (HIBP) [4, 5], a unique method for direct measurement of the electric potential in the hot plasma core. Diagnostics are separated by half of torus of the T-10 tokamak ($R = 1.5$ m, $a = 0.3$ m, $B < 2.5$ T). The top view of T-10 tokamak is shown at Fig. 1. GAMs have been studied in two plasma scenarios, presented in Figs. 2 and 3, scenario 1 with $B = 2.42$ T, $I_{pl} = 220$ kA and scenario 2 ($B = 2.2$ T, various currents $I_{pl} = 230$, 260, 280 kA).

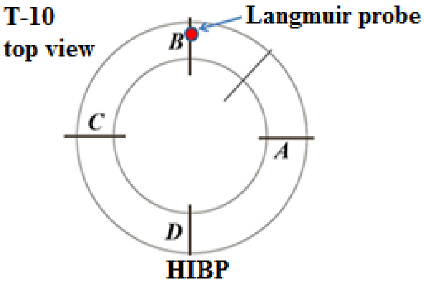

Fig. 1. The top view of the T-10 tokamak

2. EXPERIMENTAL RESULTS

It was found that coherency between signals of two diagnostics is up to 0.8. The value of coherency decreases with increasing in radial distance between HIBP sample volume and probes position at both scenarios. The phase shift between electric potential oscillation measured by HIBP and Langmuir probes has also been measured. Spectrograms of potential oscillations measured by HIBP, Langmuir probe, coherence between oscillations of potential and phase shift between them are shown in Fig. 4 and 5 for two shots from different scenarios. We assume that phase shift in toroidal and poloidal directions is equal to zero because $m = n = 0$ for GAM. So we can relate it to radial propagation of GAM. Radial distribution of coherency and phase shift for scenario 1 are shown at Fig. 6 (considered part of HIBP radial scan marked as horizontal bar). If we assume that GAM is a propagating wave we should expect phase shift $\Theta = \Theta(\Delta r_{HIBP/LP})$ is monotonous function of the distance between observation points.

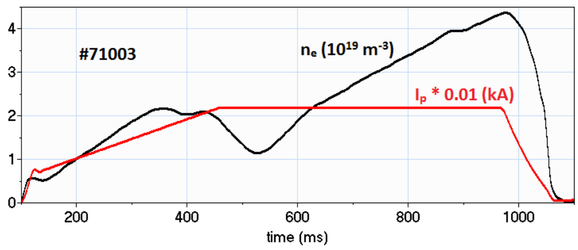

Fig. 2. Time evolution of plasma parameters in scenario 1

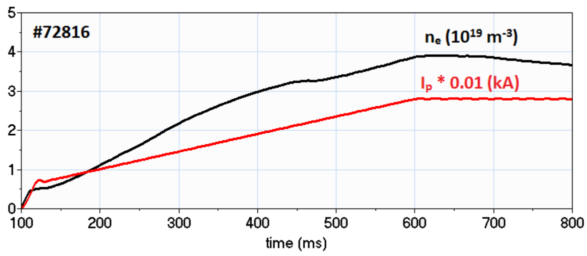

Fig. 3. Time evolution of plasma parameters in scenario 2

This is true for Θ from scenario 1. So, under this assumtion we can calculate its phase velocity by using $v = \lambda\upsilon = 2\pi\Delta r\upsilon/\Theta$, where λ – wavelength; υ – GAM frequency; Δr – radial distance between two observation points; Θ – measured phase shift. Potential oscillations at the GAM frequencies propagate outward at scenario 1 (negative Θ in case "inner point is a first argument"), the magnitudes of phase velocity are also shown at Fig. 6 (they change from ~ 2 km/s ($\Delta r \approx 2$ cm) to ~ 8.5 km/s ($\Delta r \approx 12$ cm)).

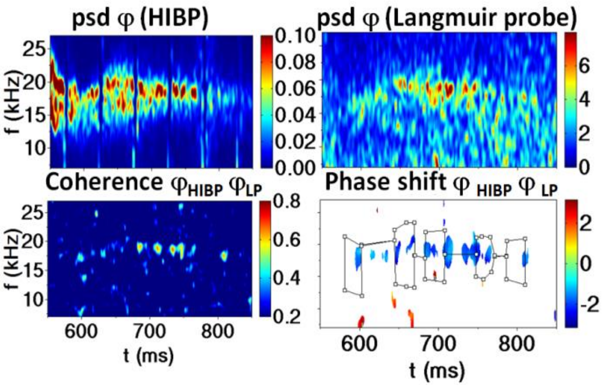

Fig. 4. Spectrograms for scenario 1 (shot #71003)

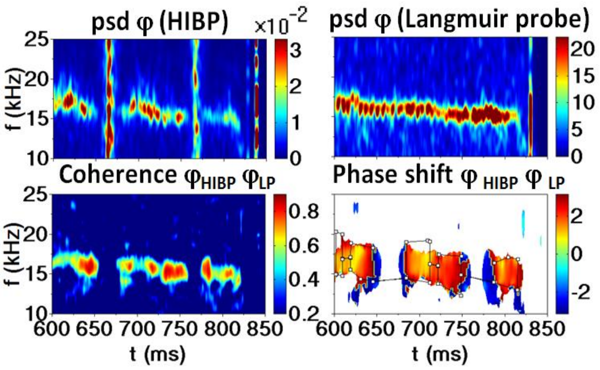

Fig. 5. Spectrograms for scenario 2 (shot #72816)

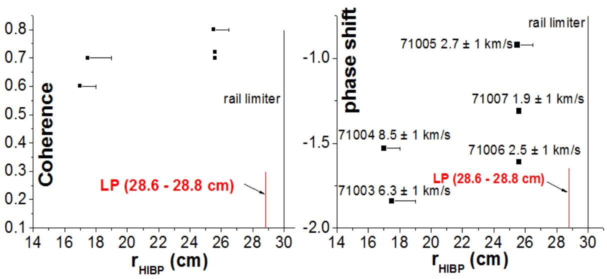

Fig. 6. Radial distributions of maximum values of coherence (averaged) and phase shifts Θ for scenario 1

The phase analysis for scenario 2 appears to be more sophisticated. The histograms of phase shifts for two typical shots are shown at Fig. 7. Note, that maximums of distribution are near ±π. These data should be analyzed in the link with the data from other shots. Radial distribution of coherency and phase shift (marked as black dots) for scenario 2 are shown at Fig. 8. Note, that for scenario 2 experimental $\Theta(\Delta r_{HIBP/LP})$ are not monotonous. Furthermore, some of them have positive values, others have negative values. So, one should take into account an ambiguity of the Θ determination with $\pm k{\cdot}2\pi$, where k is an integer number. One may add an additional phase shift $k{\cdot}2\pi$ for various k and obtain shifted data (marked as red and blue dots at Fig. 8 for k=±1). The most likely monotonous functions $\Theta = \Theta(\Delta r)$ highlighted by ellipse at Fig. 8, has k=+1, but other cases cannot be excluded.

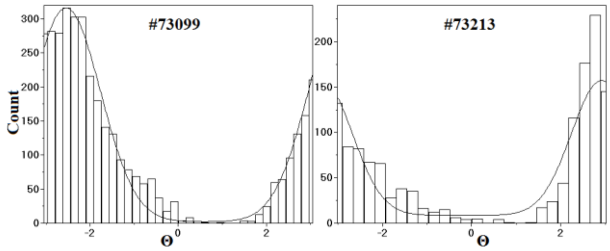

Fig. 7. Examples of histograms of phase shifts with peaks near ±π (shots from scenario 2)

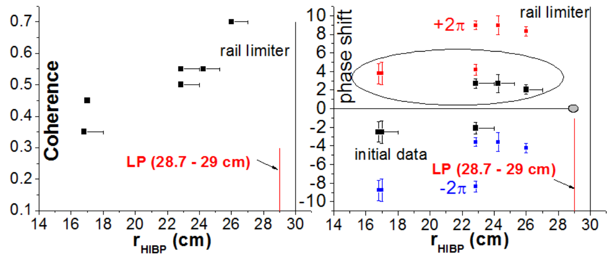

Fig. 8. Radial distributions of maximum values of coherence (averaged) and phase shifts Θ shifted by k·2π for scenario 2

3. DISCUSSION

One should consider an ambiguity of the Θ determination with $\pm k{\cdot}2\pi$ for scenario 1 also. The cases k=±1, 2 are shown at Fig. 9. The raw data (k=0) marked by black dots remain the most likely case.

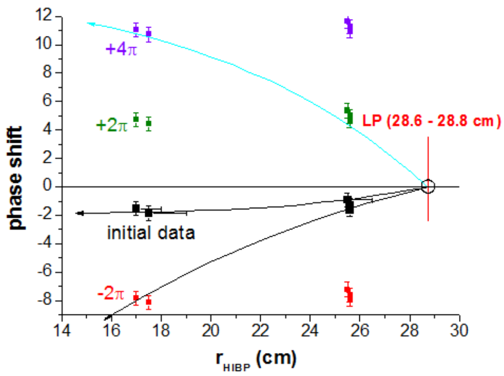

Fig. 9. Radial distributions of phase shifts shifted by k·2π for scenario 1

Finally, the direction of the plasma potential propagation in scenario 2 is still an open question. It could be an inward propagation, and a possible reason can be the difference in wall condition or n_e evolution.

CONCLUSIONS

Potential oscillations at the frequencies of the GAM have been studied with HIBP and Langmuir probes (LP) in two scenarios with close plasma parameters. The correlation between potentials by HIBP and LP is high (up to 0.8) in spite of large distance between two observation points (half of torus in toroidal and about π in poloidal direction, up to 12 cm in radial direction). In both scenarios the value of coherency decreases with increasing in radial distance between HIBP sample volume and probe positions. In the most likely case potential oscillations at the GAM frequencies propagate outward at scenario 1. The magnitude of phase velocity changes from ~ 2 km/s ($\Delta r \approx 2$ cm) to ~ 8.5 km/s ($\Delta r \approx 12$ cm) at scenario 1. There is an ambiguity in experimental data at scenario 2.

ACKNOWLEDGEMENTS

The work of Kurchatov team was funded by Russian Science Foundation (project 14-22-00193). A.V. Melnikov was partly supported by the Competitiveness Program of NRNU MEPhI.

REFERENCES

1. P.H. Diamond et al. Zonal flows in plasma – a review // *Plasma Phys. Control. Fusion.* 2005, v. 47, № 5, p. R35-R161.
2. A. Fujisawa et al. Experimental progress on zonal flow physics in toroidal plasmas // *Nucl. Fusion.* 2007, v. 47, № 10, p. S718-S726.
3. R.I. Solomatin, S.A. Grashin. Investigations of the peripheral plasma by Langmuir probes on the T-10 tokamak // *Probl. of At. Sci. and Technol. Ser. "Thermonucl. Fusion"*. 2017, v. 40, № 2, p. 43.
4. A.V. Melnikov et al. HIBP diagnostics on T-10 // *Rev. Sci. Instrum.* 1995, v. 66, № 1, p. 317.
5. A.V. Melnikov et al. Heavy ion beam probing – diagnostics to study potential and turbulence in toroidal plasmas // *Nucl. Fusion.* 2017, v. 57, № 7, p. 072004.

Article received 15.10.2018

КОРРЕЛЯЦИИ ЭЛЕКТРИЧЕСКОГО ПОТЕНЦИАЛА НА ЧАСТОТЕ ГАМ МЕЖДУ ПЕРИФЕРИЕЙ И ГОРЯЧЕЙ ЗОНОЙ ПЛАЗМЫ НА ТОКАМАКЕ Т-10

В.Н. Зенин, М.А. Драбинский, Л.Г. Елисеев, С.А. Грашин, Ф.О. Хабанов, Н.К. Харчев, Л.И. Крупник, А.В. Мельников

Работа посвящена одновременному исследованию колебаний потенциала плазмы на частотах ГАМ в различных областях токамака Т-10 и изучению их корреляционных свойств. Недавние эксперименты с использованием зондирования плазмы пучком тяжёлых ионов и ленгмюровских зондов показывают высокий уровень когерентности между сигналами двух диагностик (вплоть до 0.8), несмотря на большое расстояние между областями наблюдения: половина тора в тороидальном направлении и около π в полоидальном, до 12 см – в радиальном. Фазовый сдвиг между колебаниями потенциала, измеренный двумя диагностиками, был получен в двух плазменных режимах. Наиболее вероятно, что колебания потенциала на частотах ГАМ распространяются наружу, хотя при этом нельзя исключать влияние "перескока" фазы на 2π.

КОРЕЛЯЦІЇ ЕЛЕКТРИЧНОГО ПОТЕНЦІАЛУ НА ЧАСТОТІ ГАМ МІЖ ПЕРИФЕРІЄЮ І ГАРЯЧОЮ ЗОНОЮ ПЛАЗМИ НА ТОКАМАЦІ Т-10

В.М. Зенін, М.О. Драбінський, Л.Г. Єлісєєв, С.А. Грашін, Ф.О. Хабанов, М.К. Харчев, Л.І. Крупнік, О.В. Мельников

Робота присвячена одночасному дослідженню коливань потенціалу плазми на частотах ГАМ у різних областях токамака Т-10 та вивчення їх кореляційних властивостей. Недавні експерименти з використанням зондування плазми пучком важких іонів і ленгмюрівських зондів показують високий рівень когерентності між сигналами двох діагностик (до 0.8), не дивлячись на велику відстань між областями спостереження : половина тора у тороїдальному напрямку і близько π у полоїдальному, до 12 см – у радіальному. Фазовий зсув між коливаннями потенціалу, який вимірюється двома діагностиками, був отриманий у двох плазмових режимах. Найбільш ймовірно, що коливання потенціалу на частотах ГАМ поширюються назовні, хоча при цьому не можна виключати вплив "перескоку" фази на 2π.