Experimental study of spatial distributions of density fluctuations in T-10 tokamak and comparison between experimental results and numerical modeling

M.A. Buldakov[1], V.A.Vershkov[1], D.A. Shelukhin[1], M.Yu. Isaev[1]

[1] *NRC "Kurchatov Institute", Moscow, Russia*

1. Introduction

Correlation reflectometry experiments conducted in the T-10 tokamak showed that density fluctuation spectrum measured with correlation reflectometry can be represented as a sum of the spectra of different types of fluctuations, which have different correlational properties and spatial distributions of amplitudes. It was shown [1] that the amplitudes of some of them have high poloidal asymmetry and it may indicate that those fluctuations have different physical mechanisms at low field side (LFS) and high field side (HFS). However, one should consider non-locality of reflectometry for correct data interpretation. Reflectometry measures the integral of phase incursion averaged on certain spatial area [2]. Reflectometry signal strongly depends on the spatial structure of fluctuations. In order to study the influence of non-locality of reflectometry on the measured turbulence amplitude the modeling of turbulence structure in T-10 tokamak is needed.

2. Spatial distributions of amplitudes of density fluctuations

It was shown [3, 4] that the turbulence spectrum can be represented as a sum of 4 main types of fluctuations: broad band (BB), stochastic low frequency (SLF), low frequency quasi-coherent (LFQC) and high frequency quasi-coherent (HFQC) fluctuations. BB, LFQC and HFQC fluctuations have high poloidal asymmetry [1]. For the further investigation of physical properties of fluctuations at LFS and HFS it is of interest to obtain more detailed distributions of their amplitudes. The T-10 antennae system allows conducting measurements at 4 poloidal angles: 0°, 60°, 120° and 180°. The antenna arrays are installed at 2 poloidal cross-sections which are separated toroidally by 90°. It enabled to obtain radial and poloidal distributions of the amplitudes of BB, SLF, LFQC and HFQC fluctuations. In this paper the amplitude of the given type of fluctuations means its integral contribution to the amplitude spectrum, because it is directly measured in experiments while calculation of the relative level of density fluctuations $\delta n/n$ needs several assumptions.

Radial distributions of fluctuation amplitudes showed that LFQC fluctuations are observed in the center and periphery of the plasma column. Their amplitude has a minimum at r=22 cm. HFQC fluctuations are observed in the interval r=(16-24) cm. Radial interval of observed HFQC corresponds to the interval of minimum of LFQC amplitude. It might indicate that LFQC and HFQC fluctuations have different physical mechanisms. These results are in good agreement with the previous measurements [4]. In [4] it was also hypothesized that LFQC fluctuations correspond to ITG mode and HFQC fluctuations correspond to TEM. Poloidal distributions of amplitudes of BB and SLF fluctuations are presented in Figure 1. Poloidal distributions of amplitudes of LFQC and HFQC fluctuations are shown in Figure 2. The results of numerical simulation are also shown in Figures 1 and 2 (the simulation will be described below).

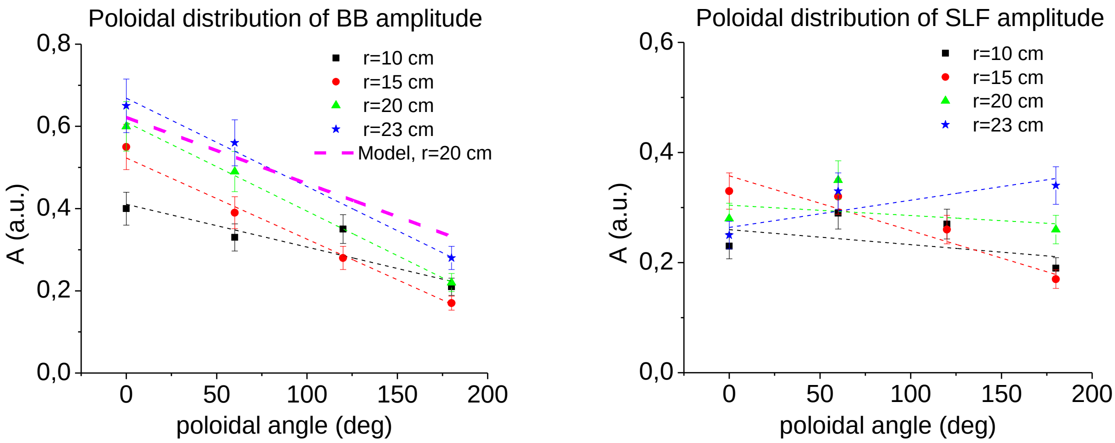

Fig. 1. Poloidal distributions of amplitudes of BB (left) and SLF (right) fluctuations. Distributions at different radii are shown by different colors. Magenta dashed line shows the results of numerical simulation.

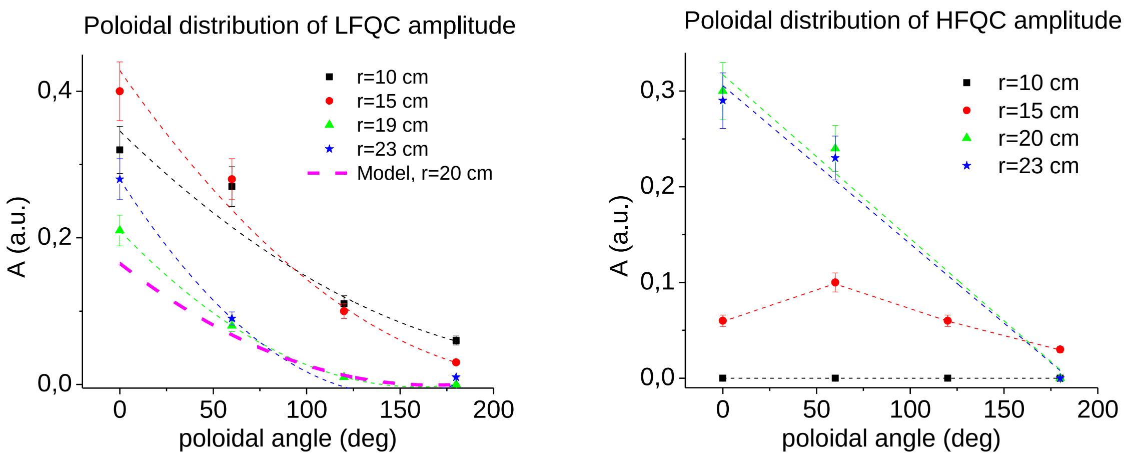

Fig. 2. Poloidal distribution of amplitudes of LFQC (left) and HFQC (right) fluctuations. Distributions at different radii are shown by different colors. Magenta dashed line shows the results of numerical simulation.

Amplitude of SLF fluctuations is independent on poloidal angle. It can be seen that BB fluctuations have poloidal asymmetry and their amplitude at HFS is about 2 times lower compared to their amplitude at LFS. LFQC and HFQC fluctuations have strong poloidal asymmetry. At the outer radii their amplitudes at HFS can be 2 orders of magnitude lower than those at LFS. Thus, the measured amplitudes of BB, LFQC and HFQC fluctuations decrease significantly at HFS compared to LFS.

3. Numerical simulation of turbulence structure in T-10 tokamak

Numerical modeling of turbulence structure in T-10 tokamak was conducted in order to take into account the influence of non-locality of reflectometry on measured amplitudes of fluctuations. In this model, BB fluctuations and one type of QC fluctuations were considered. Quasiperiodic perturbations of plasma density elongated in radial direction were generated on the calculation grid at LFS using stochastic model of density fluctuations [5]. It was assumed that the magnitudes of density fluctuations are constant along magnetic field lines and in this way the structure of fluctuations was mapped to the areas of other antennae at different toroidal angles. With the increase of the distance along the torus fluctuations incline to the radial direction due to magnetic shear. The spatial structures of a single QC fluctuation at LFS and HFS are given in Figure 3.

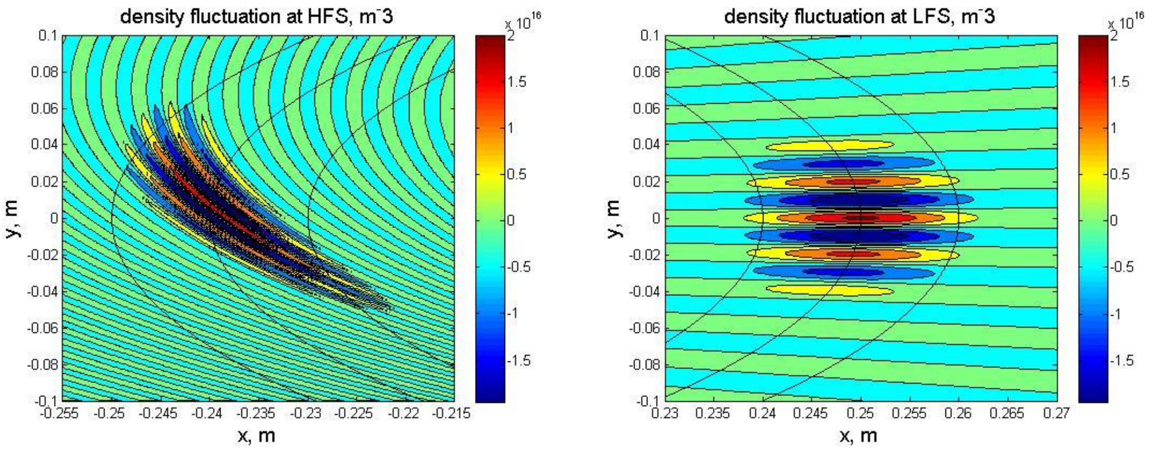

Fig. 3. Spatial structures of a single QC fluctuation at LFS (right) and HFS (left). Coordinates (x,y) correspond to the poloidal plane of the tokamak, coordinate origin is in the center of the camera. Black lines mark lines r=const.

QC fluctuations at HFS acquire oscillating structure in the radial direction along the path of propagation of reflectometry signal and integral phase incursion of the signal should decrease significantly. The fluctuations were generated at LFS on the 2D calculation grid during certain time period and 2D turbulence distributions evolving in time were obtained. Then 2D turbulence distributions were taken at fixed time moments in the time interval from 1 to 4096 μs with a period of 1 μs. Thus 4096 turbulence fields were generated and were mapped along the field lines to other poloidal angles.

The modeled reflected signals with obtained turbulent fields were obtained by means of 2D full-wave electromagnetic code Tamic-RTH for the ordinary wave [5]. Thus the time sequences of 4096 reflectometry signals were simulated. Then the spectra of modeled signals were obtained and correlation analysis of the spectra was also performed with the same technique as in experiment. The observed amplitudes of QC fluctuations in the modeled spectra decrease significantly at HFS compared to those at LFS in spite of magnitudes of fluctuations being constant along magnetic field lines. So the hypothesis of influence of non-locality of the reflectometry on the observed fluctuation amplitudes is confirmed. It should be noted that experiments and numerical modeling were conducted in the radial areas $r/a \approx 2/3$ with high magnetic shear and it explains significant change in the structure of fluctuations at HFS and decrease of their amplitudes at HFS.

Correlation analysis of modeled signals showed that radial correlation length of BB fluctuations $\Delta^{r}_{corr\,BB} \approx 6$ mm at the poloidal angle 60° LFS and it drops to 1 mm at HFS. Thus the model described above can also explain significant decrease of radial correlation length of BB fluctuations at HFS compared to that at LFS observed in experiments [1].

4. Conclusions

Therefore, the T-10 antennae system enabled to obtain detailed spatial distributions of amplitudes of BB, SLF, LFQC and HFQC fluctuations. Measurements confirmed that LFQC and HFQC fluctuations have different radial amplitude distributions and it may indicate that LFQC and HFQC fluctuations have different physical mechanisms. The measured amplitudes of BB, LFQC and HFQC fluctuations at the inner side of the torus are considerably lower in comparison with those measured at the outer side of the torus. The results of numerical simulation of turbulence structure on T-10 showed that significant decrease in the amplitudes of BB and QC fluctuations at HFS compared to their amplitudes at LFS can be explained by non-locality of the diagnostics and by transformation of turbulence structure at the inner side of the torus due to high magnetic shear. The same effects can lead to decrease of radial correlation length of BB fluctuations at HFS compared to those at LFS.

Acknowledgements

This work is supported by Rosatom Contract H.4x.44.9Б.16.1021.

References

[1]. Vershkov V.A., Andreev V.F. et al. Nuclear Fusion. – 2011. – V. 51. – 094019

[2]. Ginzburg, V.L. The Propagation of Electromagnetic Waves in Plasmas, 1964, Pergamon Press, Oxford

[3]. Vershkov V.A. et al. Rev. Sci. Instrum.- 1999 – V. 70. - № 3. – P. 1700-1709.

[4]. Vershkov V.A. et al. Nuclear Fusion. – 2005. – V. 45. - № 10. – P. S203-S226.

[5]. Urazbaev A.O. et al. Plasma Physics Reports. – 2006. – V. 32. - № 6. – P. 443-460.