# OBSERVATION OF PLASMA POLOIDAL ROTATION IN “URAGAN-3M” TORSATRON FROM EDGE $H_\alpha$ FLUCTUATION CORRELATION STUDIES

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Studies of plasma edge $H_\alpha$ emission fluctuations firstly proposed for CHS heliotron/torsatron have been performed for RF produced/heated plasma in “Uragan-3M” torsatron. Approach is based on a realistic assumption that $H_\alpha$ emission fluctuations from plasma edge ($n_e \geq 10^{17} m^{-3}$, $T_e \geq 10 eV$) defined mostly by electron density fluctuations. Having two $H_\alpha$ observation channels getting emission from plasma edge in 2 different poloidal locations of plasma one can study correlation of electron density fluctuations between these locations. Analysis of data included calculation of spectra of signals, their coherency and cross correlation between 2 signals for time windows 1 ms. Bands of rather high (>0.5) coherency were observed over the whole range (f<100 KHz) of frequencies. Calculation of cross correlation of digitally filtered ($\Delta f$=4 KHz) signals showed that time delay of low frequency part of signals coincides with time delay of no filtered signals and is decreasing with frequency increase. Conclusion of these observations is: time delay of low frequency part of signals reflects plasma poloidal rotation, time delay in the rest part of spectra reflects a dispersion properties of poloidally propagating density fluctuations.

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## INTRODUCTION

Poloidal plasma rotation induced by **ExB** drift is one of most popular topics of toroidal magnetic plasma confinement experiments. Most direct way of poloidal rotation observation is a measurement of Doppler shift of spectral lines of impurity ions emitted at corresponding direction [1]. The spatial resolution of measurements is provided by using atom beams (diagnostic or heating ones) crossing a plasma column. In this case the velocity of charge exchanged impurity ions is being measured and gives information about poloidal rotation of these ions. This velocity is not necessarily coincide with velocity of main (hydrogen) plasma ions.

Recently microwave reflectometry became popular for poloidal plasma rotation observation [2,3]. Microwave reflectometry poloidal rotation methods are based on observation on microwaves reflected by plasma cut-off layers perturbed by plasma fluctuations. Such layers act like as diffraction grating that is moving across the observation line and producing of reflected microwave modulation. Information about this movement can be inferred from observation of Doppler shifted spectrum of reflected microwaves at oblique reflection [2] or from crosscorelation of microwares reflected from two different poloidal locations [3]. In this approach the observed frequency shift or time delay are results of propagation of electron density perturbations and reflects both fluctuation poloidal propagation and plasma column rotation (if it exists).

In this work we tried to observe the propagation of electron density perturbations at plasma edge from observation $H_\alpha$ plasma emission. This approach is based on a fact that the $H_\alpha$ line intensity in a plasma with the electron temperature ≥ 5-10 eV depends on hydrogen atom and electron density only. In fluctuating plasma $H_\alpha$ light fluctuations are result of electron density fluctuations mostly thus giving a possibility to study $n_e$ fluctuations.

## EXPERIMENT

Experiments were performed during RF plasma production/heating on torsatron “Uragan-3M” (U-3M) [4]. Fig.1 shows a crossection of *l*=3 helical winding (3-rd pole is not shown) and magnetic surfaces for standard U-3M magnetic field configuration. $H_\alpha$ light emission was observed through a window by means of simple 2 channel lens+ $H_\alpha$ filter + photomultiplier (PMT) system. Each system could scan the whole plasma crossection. Signals from PMT were digitized (sampling rate up to 1.5 M 12b words/s), stored and analyzed.

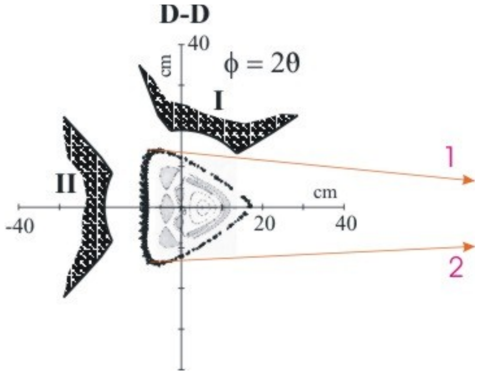

*Fig.1 Schematic view of experiment (1.2- observation lines).*

Typical $H_\alpha$ signal for experiment (B=0,7 T, $P_{RF} \leq 200$ KW) is shown on Fig.2 together with signal of 2 mm interferometer. Shot-to-shot scanning of observation line (for both channels) (Fig.3) allowed choosing positions of channels for observation of light from opposite lobes of magnetic surfaces.

Analysis of fluctuations included calculation of power spectrum of $H_\alpha$ signals, cross-correlation $C_{12}(\tau)$ and coherence function $C_{12}(\omega)$ of 1024 data points cut out of signals (sampling rate – 1 Mw/s).

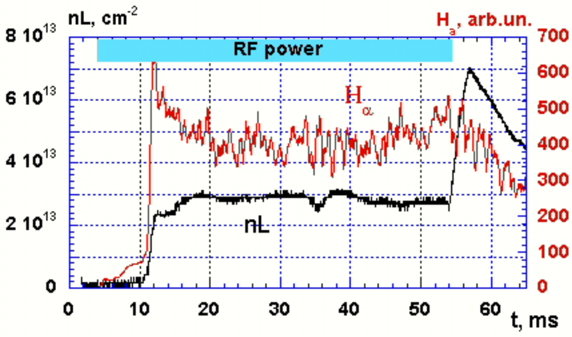

*Fig.2 Typical signals of $H_\alpha$ and 2 mm interferometer (sampling rate- 200 Kw/s)*

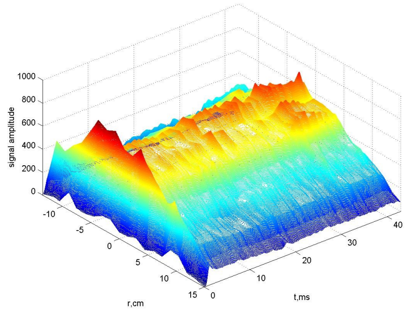

*Fig.3 Contour plot of side-on observation of $H_\alpha$ emission.*

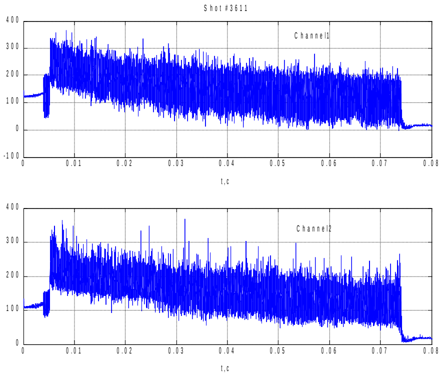

*Fig.4 $H_\alpha$ signals for both channels (sampling rate – 1 Mw/s).*

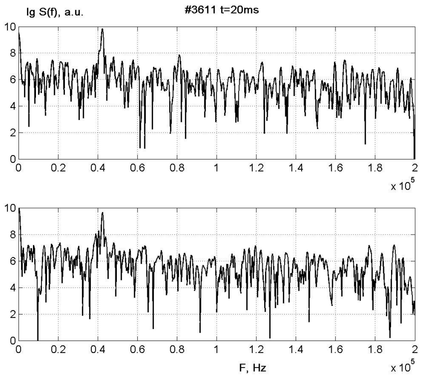

*Fig.5 Spectra of signals of both channels.*

Typical spectra of $H_\alpha$ light fluctuations are shown (in log scale) on Fig.5. These spectra are characterized by slow decrement in frequency domain and do not depend on time during 20-50 ms. Cross-correlation between signals for the same time window is shown on Fig.6.

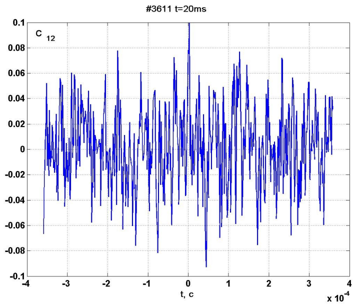

*Fig.6 Cross-correlation between signals.*

The most striking feature of cross-correlation between $H_\alpha$ signals from different poloidal locations – maximum at zero lag time. This means that other then poloidal propagation manifests itself in observed fluctuations (possibly ballooning mode). Poloidal propagation of density perturbations can be responsible for other maxima of $C_{12}(\tau)$.

To get more information about poloidal propagation of perturbations we used another approach – filtering of rather narrow frequency bands (δf=2-3 KHz) of signal and calculation of time lag between these filtered signals. At this approach we used the numerical double filtering procedure that eliminates the phase delay produced by signal filtering. Typical cross-correlation for filtered signals is shown on Fig.7.

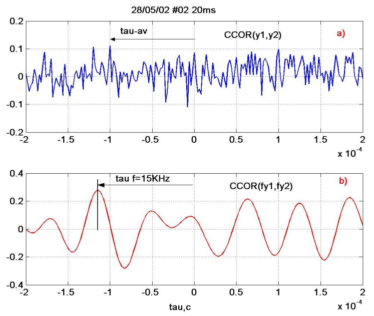

*Fig.7 Cross-correlation for non-filtered (a) and filtered (f=15 KHz) signals.*

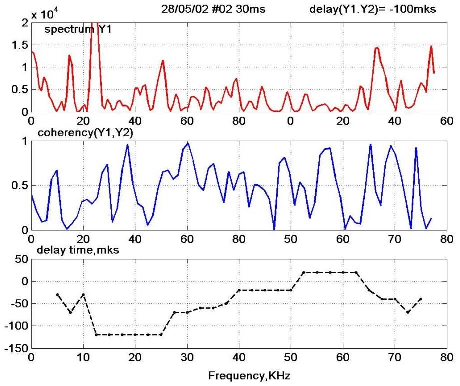

*Fig.8 Power spectrum, coherency function and time lag spectrum of $H_\alpha$ light fluctuations for t=20ms*

Results of calculations of time lag for filtered signals depending on filter frequency $\tau_{12}(f)$ together with power spectrum and coherency function are shown on Fig.8.

Analysis of data for different shots and time intervals for given shot allowed us to distinguish 3 frequency bands: 1) low frequency (12-25 KHz) band with almost constant delay time ($\delta\tau=-120$ mks); 2) intermediate frequency (25-50 KHz) band with changing delay time and 3) high frequency (52-60 KHz) band with small delay time ($\delta\tau=20$ mks). As for as the delay time in the band 1) roughly coincide with one of maximums in cross-correlation for unfiltered signal, we suggest that poloidal plasma rotation is responsible for this delay time. In its turn small delay time in band 3) might reflect existence of zero lag time maximum in cross-correlation for unfiltered signal and thus corresponds to ballooning mode of perturbations. We also suggested that band 2) with changing delay time reflects an existence of perturbations propagating in poloidal direction. Data for delay time in this band were used for calculation of velocity of propagation $v$ and "dispersion relation" for this frequency band

$$\omega = k \cdot v$$

Fig.9 illustrates results of these calculations (points). For poloidal modes one can suggest that

$$k = \frac{m}{a} \quad (1)$$

where $m$ – mode number (1,2,..) and $a$ – plasma layer radius ($a \approx 12$ cm). Horizontal lines on Fig.9 shows $k$-values calculated from eq. (1). One can notice that mode frequencies (intersections points of dotted line and horizontal bars) roughly coincide with spectrum and coherence function maximums in band 2).

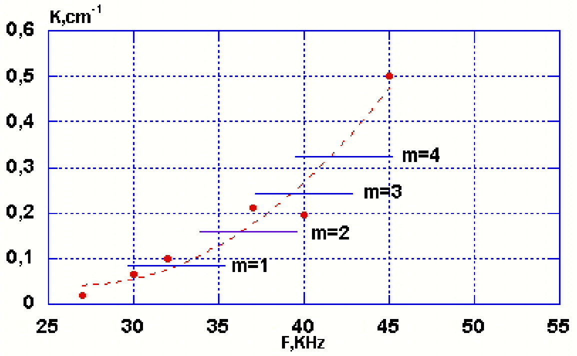

*Fig.9 $K_\theta$ spectrum for f=27-45 KHz.*

## CONCLUSION

Studies of properties of fluctuations of $H_\alpha$ light emitted from edge plasma in U-3M torsatron showed rather complicated picture that did not allow distinguishing effects of possible poloidal plasma rotation from data of cross-correlation analysis. We introduced a new function – time lag spectrum $\tau_{12}(f)$ and calculated it by using digital filtering of $H_\alpha$ signals. This function appeared to give information about different modes of perturbations - poloidally propagating and ballooning modes and poloidal plasma rotation. Such approach can be used for fluctuations observed by any diagnostic if it has a good spatial and time resolution and has at least 2 space separated observation channels.

Poloidal rotation velocity value inferred from time delay of low-frequency part of $H_\alpha$ fluctuation spectrum ($v_{pol} \approx 3$ km/s) well agreed with data obtained for U-3M torsatron via poloidal correlation microwave reflectometry [4].

The main disadvantage of $H_\alpha$ light usage – the lack of good spatial distribution – can be overcame by BES (by using diagnostic or heating neutral beam).

Similar setup for $H\alpha$ observation is under preparation for the CHS Heliotron/torsatron now.

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