Application of Doppler backscattering for Alfvén mode investigation on the Globus-M tokamak

V.V. Bulanin[1], V.K. Gusev[2], G.S. Kurskiev[2], V.B. Minaev[2], M.I. Patrov[2], A.V. Petrov[1], M.A. Petrov[1], Yu.V. Petrov[2] N.V. Sakharov[2], P.B. Shchegolev[2], V.V. Solokha[2], A.Yu. Telnova[2], S.Yu. Tolstyakov[2], A.Yu. Yashin[1].

[1] *Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia*

[2] *Ioffe Institute, St. Petersburg, Russia*

The excitation of Alfvén modes (AM) in a tokamak adversely affects the confinement of energy ions [1]. Thus, nowadays AM diagnostics is developing actively. Along with the traditional methods such as Mirnov probes, novel methods of detecting and investigating AM in the central regions of tokamaks are emerging. These include reflectometry [2], HIBP [3], ECE diagnostic [4]. Recently Alfven waves were detected by the Doppler backscattering (DBS) diagnostics [5]. This paper presents the results of Alfven modes studying by multi-frequency DBS system in the spherical Globus-M tokamak.

Globus-M regime with Alfven eigenmodes, typically detected by Mirnov probe array as TAE modes [6], [7] was chosen for investigations. The experiments were performed in Globus-M deuterium plasmas with NBI heating under the following discharge parameters: I_p = 170-250 kA, $n_e < 5\times10^{19}$ m^{-3}, and B_T = 0.4 and 0.5 T. The deuterium beam with the energy E_b=28 keV and power P_b=0.75 MW was used for auxiliary heating. Alfvén modes were observed in the discharge as lonely bursts of magnetic probe signals. The corresponding probe signals and its spectrograms are presented in Figure 1 b and c.

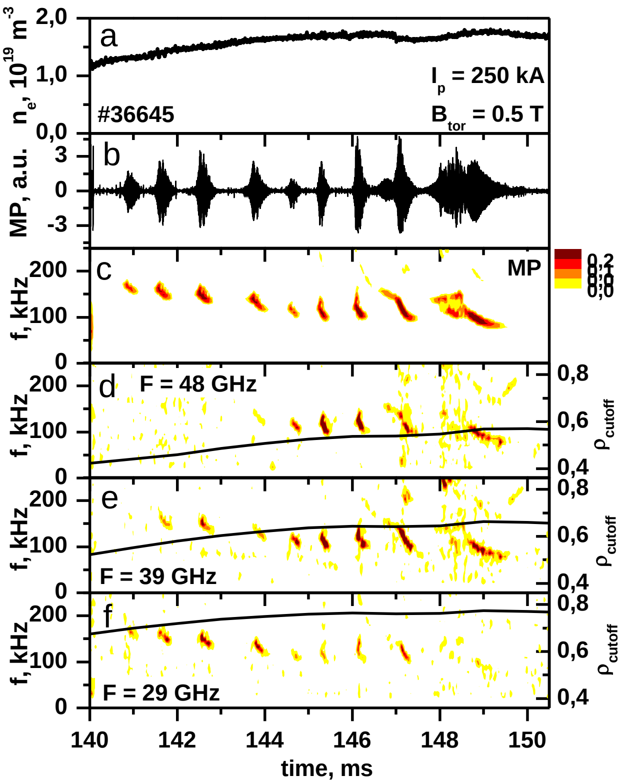

Figure 1. a - line averaged electron density, Mirnov probe signal, c – spectrogram of magnetic TAE oscillation, d, e, f, perpendicular velocity oscillations ant corresponding cut-off radius displacement.

It is well known that DBS allows determining of the perpendicular rotation velocity $V_\perp$ of plasma fluctuations responsible for scattering of microwave radiation. Doppler shift of microwave radiation backscattered from cut-off region provides information for $V_\perp$ evaluation (see for example [8]). If rotation is due to the drift in a radial electric field, it is possible to measure the magnitude of this field. In addition, diagnostics allow estimating of the radiation intensity scattered from fluctuations in the chosen band of wave numbers. Consequently, if the Alfvén modes cause oscillations in the fluctuation velocity $V_\perp$, or oscillations in the backscattered radiation intensity at the Alfvén frequencies, recording of Alfven modes by DBS method is possible.

The four-frequency DBS diagnostics system was used in the Globus-M experiments. Each channel includes a microwave circuits with a dual homodyne IQ detector of the backscattering radiation. Four fixed probing frequencies of 20, 29, 39 and 48 GHz were used [8]. A steerable antenna was used to probe the plasma by O-mode radiation from the low magnetic field side. To estimate the cut-off position and the wave number of the scattering fluctuations, 3D ray tracing was carried out using the magnetic configuration data from the EFIT code [8]. The locations of cutoff layer were in the range of normalized minor radii ρ = 0.5 - 1, while the scattering wavenumbers were in the range of $k_\perp = 2 - 6\ cm^{-1}$.

Perpendicular velocity $V_\perp$ oscillations at the Alfven mode frequencies were revealed using the multi frequency DBS. These oscillations were observed simultaneously with Mirnov probe signal bursts. Clear time correlation is demonstrated in Figure 1 for the case of plasma probing with radiation of three different microwave frequencies. Figure 2 shows the spectra of the magnetic probe signals (Figure 2a) and the velocity oscillation spectra (Figure 2b, c) calculated at the equal time sample of 64 µs. Relevant cutoff layer positions are also marked on this figure. One can clearly see the coincidence of the peaks in the spectra of the magnetic fluctuations and perpendicular velocity $V_\perp$ at 90 kHz for the cutoff position at 51.8 cm and its harmonics for the cutoff at 54.1 cm. This

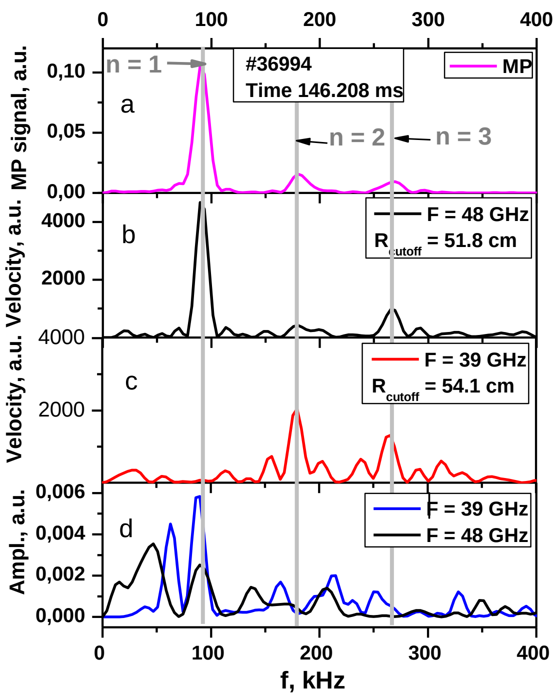

Figure 2. Power spectra of Mirnov probe signal (a), perpendicular velocity (b, c), amplitude of fluctuations (d). n is toroidal wave number.

may be explained as different localization of Alfven modes with different toroidal numbers n. The n-values were determined using the Mirnov probe array. It was noted that there is also a peak at the frequency of 90 kHz in the spectra of the amplitude of backscattered signals (see Figure 2a and d). However, the contrast of this peak was significantly lower than the velocity peak.

We believe that observed velocity oscillations at the frequency of Alfvén modes are related to the oscillations of the E×B drift in a radial electric field of Alfvén wave. The possibility of existence of such oscillations is indicated by measurements performed earlier using the HIBP diagnosis [3]. Using this assumption on the velocity oscillations nature, it is possible to estimate the amplitude of the radial electric field oscillations, $\tilde{E}_r = \tilde{V}_{\perp} B$. and to estimate the amplitude of oscillations of the poloidal projection of the magnetic field in the electromagnetic Alfvén wave $\tilde{B}_\theta = \tilde{E}_r / V_A$ (V_A is the Alfvén velocity). Comparison of $\tilde{B}_\theta$ amplitude estimated from DBS data and evaluated from measurements of magnetic probes located at the radius, R = 62.5 cm is presented in Figure 3. One can see that the amplitude of fluctuations measured by DBS is higher than those measured by magnetic probes. This means that fluctuation amplitudes are diminish towards plasma periphery, where magnetic probes are positioned.

Assuming that the perpendicular components of the magnetic field in the Alfven wave are approximately the same, $\tilde{B}_\theta \approx \tilde{B}_r$, one can estimate radial displacement of the probing radiation cutoff position caused by the Alfven mode. It does not exceed 1 mm. Such a small displacement obviously could not initiate the perpendicular velocity and amplitude modulations comparable to experimentally observed. On the other hand, a variable radial component of magnetic field $\tilde{B}_r$ in the Alfvén wave leads to deformation of the magnetic surface, which finally should result in changing of scattering fluctuation k-value. Maximal relative k-value change may be estimated as, $\Delta k/k \approx \tilde{B}_r / B_\theta \approx \tilde{B}_\theta / B_\theta \approx 10^{-2}$. In this case expected amplitude of the velocity oscillations is $\tilde{V}_{\perp} \approx 10^{-2} < V_{\perp} >$, where $<V_{\perp}>$ is the average rotation velocity of the plasma. However, much larger values of $\tilde{V}_{\perp} \approx (0.5 \div 1.5) < V_{\perp} >$ were observed in the experiment.

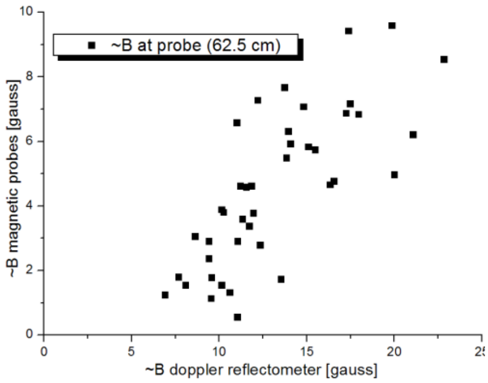

Figure 3. Comparison between $\tilde{B}_\theta$ amplitudes measured by Mirnov probes and DBS.

Neither the cutoff position displacement nor small changes of k-value could explain experimentally observed values of $\tilde{V}_{\perp}$, so we believe that velocity fluctuations are oscillations of the drift velocity in a radial electric field. Changes of k-value could principally effect the modulation of backscattered radiation level in the case, when amplitude of scattering is strongly dependent on k-value. Therefore, it is possible that observed small oscillations in the amplitude of the detector signal at the Alfven frequency are due to that reason.

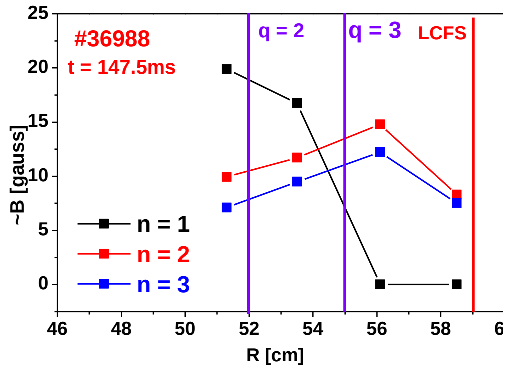

Figure 4. Radial locations of TAE modes as functions of estimated $\tilde{B}_{\theta}$ vs R.

A multi-frequency DBS scheme allowed estimating of TAE spatial location. As it is seen from Figure 1, the velocity oscillations at Alfven frequency are registered first by the low-frequency (28 GHz) DBS channel, and then with a delay by higher frequency channels. Such an evolution apparently indicates the development of TAE (n = 1) in the region, R = 48-51 cm (ρ = 0.5 – 0.7 see Figure 1), which is intersected by the cutoff surfaces for higher probing frequencies, while the density increase. A more detailed example of TAE location for different toroidal mode numbers is presented in Figure 4, which demonstrates that spatial position of toroidal Alfven mode with n = 1 number is placed closer to the plasma center. Details of the Alfven mode spatial distributions are discussed in the report [9].

In summary, current results demonstrate the successful application of the multi-frequency DBS for Alfvén mode study. Further development of the DBS diagnostics for the systematic exploration on the modernized spherical Globus-M2 tokamak requires increasing of frequency channels number to achieve better spatial resolution and application of higher probing frequencies for reliable identification of TAE in plasma with higher density.

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