PLASMA OSCILLATIONS PROPAGATING ALONG THE MAGNETIC FIELD IN THE URAGAN-2M TORSATRON

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The spectral and correlation analysis were applied to study interferometry data measured in two toroidally spaced transverse sections. The oscillation frequency increase for higher magnetic field and decrease with density rising which cold be attributed with existance of Alfven eigenmodes. Calculated frequency values cold be higher that from spectral analysis. This may be due to presence of impurities in plasma.

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INTRODUCTION

The tokamak experiments have revealed the existence of longitudinal waves, the excitation of which is connected with the presence of energetic particles in plasma; therefore, they are also identified as energetic particle modes or Alfven eigenmodes [1]. The first observations of Alfven eigenwaves in stellarators were made at W7-AS [2], where the so-called global Alfven eigenmodes were excited by a high-energy ion beam. In his monograph [3], K. Miyamoto has demonstrated the possibility for existence of the toroidicity-related Alfven-wave discrete eigenfrequency or the toroidal Alfven eigenmode (TAE-mode). The occurrence of energetic particle modes in the U-2M facility may be possible, because with a similar method of plasma generation, energy of ions much higher than the ion temperature values were observed in the U-3M torsatron [4].

The present work is a continuation of the previous studies [5] based on the experimental data obtained in 2008 at the Uragan-2M torsatron, and is devoted to investigating the discovered oscillations that are propagating along the magnetic field.

PLASMA OSCILLATION ANALYSIS

In the U-2M torsatron experiments, the plasma was generated by RF fields of frequencies below Alfven frequencies [5] excited by two antennas, namely, K1 antenna having a wide wavelength spectrum (λ= 80…1068 cm), and K2 antenna having a narrow spectrum (λ= 50…120 cm). As the quasi-stationary discharge phase of density (2…3.5)×10^{12} cm^{-3} was attained, the fluctuations of up to 300 kHz of the transmitted microwave were observed. The detected oscillations cannot be identified as the previously observed low-frequency fluctuations of up to 60 kHz. For registration of the oscillations, the microwave interferometry in two toroidally spaced transverse sections was used, succeeded by the correlation/spectral analysis. The microwave probing scheme is presented in Fig. 1. The magnetic surface structure is conventionally shown by oval curves. The microwave interferometry in use enabled us to measure the mean density along both the chord passing through the magnetic axis, where the density is maximal, and the chord displaced from the magnetic axis by a distance of 8.2 cm. The ratio of mean densities on the two chords makes it possible to judge whether the peak density is on the magnetic axis or is displaced from it.

The two-chord interferometry provides information on the density profile if it is represented as:

\[ N(r) = N_0 \cdot [1 - (r / a)^q], \]

where \( N_0 \) is the maximum density, \( a \) – is the radius of the extreme undamaged surface, \( q \) – is the exponent.

With two-chord mean density measurements by microwave interferometers, the parameters \( N_0 \) and \( q \) are determined from the following formulas:

\[ \frac{\bar{N}_{\text{later}}}{\bar{N}_{\text{centr}}} = \frac{q + 1}{q} \left\{ \frac{1}{a - \bar{r}} - \frac{1}{a - \bar{r} + 1} \left[ 1 - \left( \frac{\bar{r}}{a} \right)^{q+1} \right] \right\}, \]

\[ \frac{\bar{N}_0}{\bar{N}_{\text{centr}}} = \frac{q + 1}{q}, \]

where \( \bar{a} \) – is the mean radius of the last undamaged surface, \( \bar{r} \) – is the minimum spacing between the magnetic axis and the lateral chord.
where δN is the density fluctuation dispersion, N and \( N_{cr} \) are the present density and critical density, respectively. The depth of modulation increases when the \( N/N_{cr} \) ratio approaches 1. In this case, the condition \( \delta N << N_{cr} - N_m \) should be met, where \( N_m \) is the highest density in the layer, and the modulation period \( T_m \) is much greater than \( T \) - the wave travel time in plasma. The calculations described in ref. [6] show that at \( T_m/T \approx 30 \) the frequency measurement error is insignificant.

The plasma oscillations were investigated through plasma probing by electromagnetic \( \lambda = 8.2 \) mm waves along the central chord in one cross-section, and by \( \lambda = 12.1 \) mm waves in the other cross-section along the chord displaced outwards. The mean density was measured on the central and lateral chord, and wave fluctuations were detected. The experimental results underwent the spectral and correlation analysis. The characteristic interferometer signals (responses) in the two cross-sections are shown in Fig. 2. For the analysis of plasma oscillations we have chosen the two interferometer signal regions (Fig. 3) having the densities \( N_c = 2 \times 10^{12} \text{ cm}^{-3} \) and \( N_l = 1.7 \times 10^{12} \text{ cm}^{-3} \) on the central and lateral chord, respectively. The mean density value \( N = 1.8 \times 10^{12} \text{ cm}^{-3} \) between the chords was reached within 2.9 to 4.8 ms from beginning of the discharge, depending on the magnetic field value (Fig. 4). At the voltage \( U = 0 \) on the antenna K1, the density \( N_c \) is higher than \( N_m \), i.e., a hollow density profile was formed, showing a higher level of fluctuation intensity on the lateral chord than the one on the central chord. At \( U = 5 \) and 4 kV on the antennas K1 and K2, respectively, the density \( N_l \) is higher than \( N_m \), and the oscillation intensity is stronger on the microwave beam that travels along the central chord than the intensity along the peripheral beam.

The analysis of microwave signals transmitted through the plasma has shown that in the neighborhood of the maximum discharge density there occur oscillations of \( \sim 100 \) kHz frequency and higher in each channel. To be sure that the oscillations are propagating along the torus, studies were made into the coherence functions (Fig. 5), cross-correlation functions of microwave signals and the cross spectra (Fig. 6).

The fluctuation spectra were determined from the Fourier analysis of fluctuations of plasma-transmitted microwave signals in the length intervals of 64 and 128 µs, where the plasma was quasi-stationary. The oscillation characteristics were measured at different magnetic fields for a density of \( 1.8 \times 10^{12} \text{ cm}^{-3} \), and also in a single discharge versus density. It is shown that the oscillation frequency increases with an increase in the magnetic field, and decreases with an increasing plasma density as in the case of Alfvén eigenmodes (Figs. 7, 8). Frequencies approaching two- and three-fold frequency values were also observed. The frequencies of cross spectra were in agreement with the frequencies observed in the two channels. The oscillations of up to 60 kHz are independent of the magnetic field value.
In the case of Alfven waves, the dispersion relation has been made between the calculated (by eq. (4)) and experimentally measured plasma density values (see Fig. 7). According to formula (5), at B=0.45 T in the range $t = 4...8$ ms we have $N = (1.85...2.02)10^{12}$ cm$^{-3}$, $\mu_{ef}=1.15...1.3$.

CONCLUSIONS

Longitudinal oscillations of torsatron U2-M plasma have been investigated on the basis of microwave interferometry signals in two cross-sections spaced apart along the torus axis. The oscillations have been shown to propagate along the torus, and are believed to bear the marks of Alfven eigenmodes. The effective ion-to-proton mass ratio has been estimated.

REFERENCES


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