Alfven instabilities in hydrogen, deuterium and helium plasmas in ohmic regime of TUMAN-3M tokamak

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Alfven waves (AWs) are usually observed in magnetically confined plasmas with noticeable content of energetic ions produced by auxiliary heating [1]. Several reports on observations of AWs in ohmically heated plasmas, where amount of energetic ions is thought to be negligible, should be mentioned [2,3,4,5]. In spite of the above efforts mechanism of AWs excitation without presence of superthermal ions is not fully understood. Further studies of Alfven waves in conditions of ohmic heating may shed light on the mechanism.

Observation of bursting and quasi-continuous Alfven waves in ohmic plasma

TUMAN-3M is a compact limiter tokamak of circular geometry: R_0/a_l = 0.52/0.22 *m*. AWs were observed in the discharges with following plasma parameters: $B_T = 0.7 \div 1.0$ *T*, $I_p = 130 \div 150$ *kA*, $0.2 \le n_{e,av} \le 2\ 10^{19} m^{-3}$, $T_e(0) = 0.45 \div 0.7$ *keV*, $Ti(0) = 0.15 \div 0.2$ *keV*. High frequency magnetic oscillations have been observed in ohmic plasma using magnetic probes sited inside vacuum vessel. Frequencies of the oscillations are within 0.8-1.8 *MHz* range which is two orders of magnitude above the typical frequencies of tearing mode activity in the tokamak. Amplitude of the oscillations was found to increase with decreasing density. Frequency (f) of the oscillations is proportional to Alfven speed (V_A) when toroidal magnetic field and density are varied. The dependence allowed identifying the oscillations as manifestation of Alfvenic waves excitation [6].

In many cases AWs reveal themselves as bursts of oscillations strongly linked to the moments of sawtooth crashes, see Fig.1. In this figure sawtooth activity is illustrated by density trace (bottom plot) which characterized by slow increase in the average density during a quiet portion of ST cycle and quick drop of the density in the reconnection phase. Each reconnection event is found to accompany with a short burst of magnetic oscillations of 1 *MHz* frequency range, which is clearly seen on the fast magnetic probe signal spectrogram (top plot). Burst duration is in the range of 0.1-0.2 *ms*, what is comparable to reconnection phase duration in typical conditions of TUMAN-3M. In some cases burst may persist longer than reconnection phase duration, see, for instance, bursts on 47.4, 52.0, 56.3 *ms*, where bursts duration is more than two times longer compared to reconnection time. Other feature of

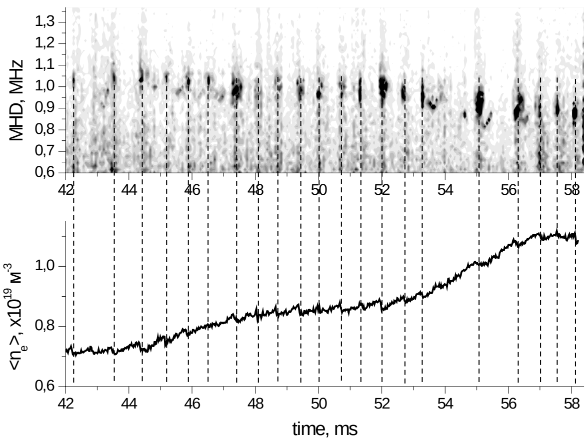

Fig.1 Spectrogram of AWs: bursts coincide with sawtooth crashes as indicated by vertical lines pointed on density drops caused by the crashes.

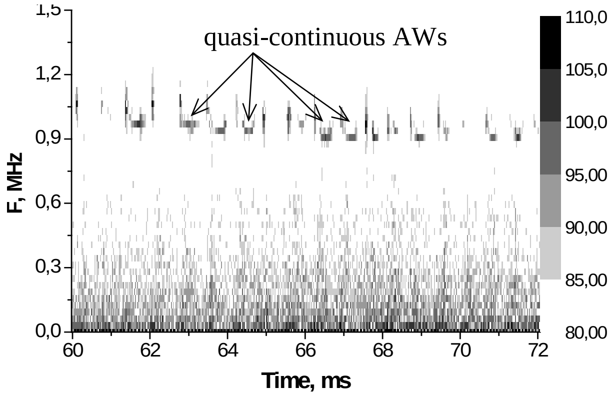

Fig.2 Spectrogram of AWs: quasi-continuous patches exist between ST crashes. Width of their spectra is narrower than during bursts: 0.02-0.04 MHz

the AWs is relatively large width of oscillation spectra: 0.2÷0.4 *MHz*. The feature indicates excitation of multiple trains of AWs with different frequencies during ST crash phase.

Besides the bursting AWs, the patches of quasi-continuous oscillations were detected, see Fig.2. The oscillations start 0.1-0.2 *ms* after ST crashes and persist 0.3-0.8 *ms* until next ST crash. Width of their spectra is by an order of magnitude narrower than in bursting cases: 0.02-0.04 *MHz*. The oscillation frequency is ~ 20% lower than frequency of bursting AWs in the same shot and shows reproducible behavior within ST cycle: first, it goes down and then, approximately at the middle of ST period starts to increase. The relative frequency change is 10-20%.

Strong correlation between intensity of stray X-ray intensity and AWs amplitude (the both bursting and quasi-continuous) is found. Measured flux of X-ray photons has spectrum range of 0.2÷2.0 MeV which is formed by photon scattering in metallic structures. The photons in turn are produced by runaway electrons (REs) which hit Mo limiter. Assumption of correlation between volume REs and the REs interacting with the limiter allows conclusion on existence of correlation between AWs amplitude and amount of volume REs. This correlation points on volume REs as possible source of drive for AWs. Although specific mechanism of Alfven waves excitation by runaway electrons should be further clarified.

Alfven waves in helium plasma

In [6] the conclusion on Alfven nature of observed high frequency magnetic oscillations was made on the base of linear dependence of frequency on Alfven speed in the both hydrogen (H) and deuterium (D) plasmas:

$$V_A = \frac{B_T}{\sqrt{\mu_0 \cdot m_i \cdot n_i}} \quad (1)$$

The study has shown close to linear dependence of frequency *f* on V_A for the both working gases. Helium (He) as a working gas differs essentially from hydrogen isotopes since (1) its nuclear charge is 2*e* and therefore ion density is only half of electron density in a tokamak plasma, (2) its mass is four times of hydrogen mass what should lead to significant extension of Alfven speed range, (3) atomic properties and recycling of He is much different from hydrogen isotope ones what may result in significant changes of density/temperature profiles. Above considerations motivates experiments on AWs detection in He plasma.

In the recent experiments the data base of observations of high frequency oscillations was extended by inclusion of a set of discharges produced with He working gas. He discharges were found to have a bit higher electron temperature: $T_e(0) \approx 1.0$ *keV* compared to 0.6 *keV* in D shots with similar B_T, I_p, $n_{e,av}$. Also some decrease in sawtooth inversion radius was found indicating more peaked electron temperature profile in He. In spite of the mentioned differences high frequency oscillations properties did not change much. Range of observed frequencies does not change from that in H/D shots. Figure 3 shows combined data collection in frequency vs Alfven speed plot. In the figure red triangles representing He shots lie in the well populated area of H/D shots with *f* close to 1 *MHz* and $V_A = 2.7 \div 4.7 \cdot 10^6$ *m/s*. The He shots fairly good overlap with H whereas D points concentrated at slightly bigger frequencies. Less peaked profiles in D plasma with high density might explain the offset. Effect of the correction for profile peakedness on observed deviation of D shots will be analyzed elsewhere. Good overlap of frequencies in H/D and He shots indicate significance of

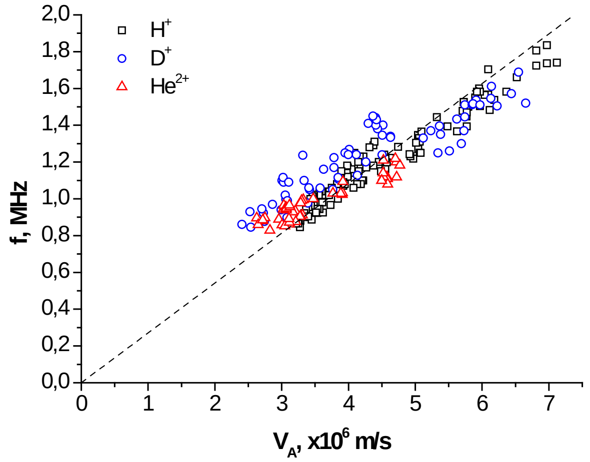

Fig.3 Dependence of oscillation frequency on Alfven speed in hydrogen – black squares, deuterium – blue circles and helium shots – red triangles

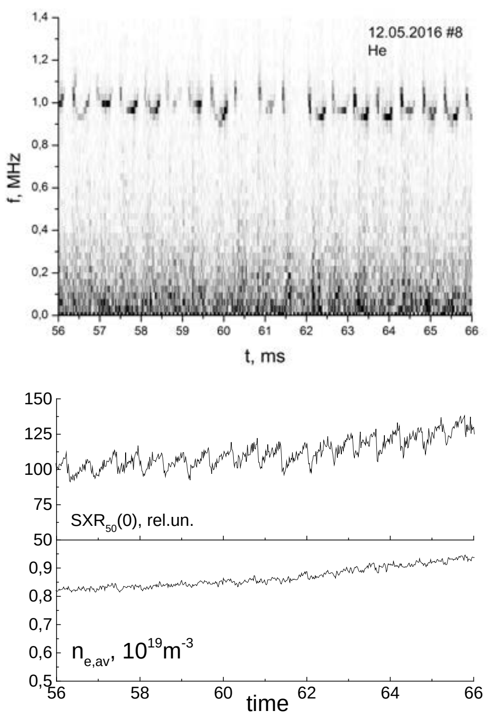

Fig.4 Spectrogram of AWs (top right), ST oscillations illustrated by SXR signal (middle right), density evolution in helium plasma (bottom right)

magnitude of Alfven parameter in defining a resonance frequency but not in identification of drive source. Similarity of AWs in plasmas with different working gases is further corroborated by comparison of spectrograms of oscillations observed in D (Fig.2) and in He (Fig.4). Similar to D spectrogram two types of oscillations could be identified in He: bursting – excited during ST crash phase and quasi-continuous existing in quiet phase of ST cycle. The later are characterized already mentioned feature: some decrease in frequency in postcrash phase followed by frequency increase in the phase preceding next crash.

Conclusions

Reported observations of Alfven waves excitation in ohmically heated TUMAN-3M tokamak are of interest since AWs are usually excited by energetic particles produced in experiments with strong auxiliary heating and thus are unexpected in ohmic regime. Performed study has confirmed Alfvenic nature of the oscillations observed in [6]. Experiments with He plasma suggest similarity of Alfven waves observed in plasmas with different working gases: two types of AWs existing in ST crash phase and in quiet ST cycle phase; close overlap of arrays of points corresponding to H, D and He on a frequency vs Alfven speed diagram. The similarity indicates independence of AWs driving mechanism on sort of plasma ions. Tendency of increase in the amplitude of the AWs with decreasing density, correlation of the amplitude with runaway electrons amount together with above mentioned independence of driving mechanism on sort of ions allowed to conjecture that fast electrons provide necessary source of drive for AWs observed in ohmically heated tokamak. Although mechanism of Alfven waves excitation is not evident at the moment and should be further analyzed.

Acknowledgement

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