Observation of High-Frequency Oscillations in the TUMAN-3M Ohmic Plasmas

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ABSTRACT

- Magnetic oscillations in frequency range of 0.3 to 1.25 GHz have been found in ohmic plasma with low density, (0.5-1.3)·10^{19} m^{-3}. Spectrum of the oscillations has comb-like structure with frequency gaps of 15-35 MHz.
- The emission is characterized by a bursty behavior. Appearance of the emission were found to correlate with bursts of Gamma-rays produced by runaway electrons (RE) with energy of 4-5 MeV.
- Whistler waves excited by RE are considered as a possible explanations for the oscillations. Comb-like structure is conjectured to be caused by cavity of the tokamak vessel.

1. Introduction

- The first mentions of waves excited by accelerated electrons appeared long time ago [1]. The waves are observed in cosmic [2], atmospheric [3] and laboratory plasmas [4,5,6]. Such waves, arising in the frequency range of $\omega_{ci} < \omega < \omega_{ce}$, are whistlers or high frequency electron plasma waves [7,8,9]. The dispersion of these waves is described by the wave equation for cold magnetized plasma [10,11].
- The importance of studying whistlers is due to the possibility of using them for angular scattering of runaway electrons (RE) [5,8], which are extremely dangerous for the first walls of modern and future thermonuclear devices [12].
- In tokamaks, whistlers have been observed in DIII-D [6,9], FTU [13,14], FT-2 [15]. RE driven instabilities causing rapid increase of the perpendicular energy, so called "fan" instabilities, were observed in the early tokamaks as well [16,17]. Theory describing the experiments by excitation of magnetized electron plasma waves was developed [18] though frequencies of these waves are substantially higher than the whistlers' ones.
- Besides, two types of high frequency magnetic oscillations have been found in the experiments with low-density ohmic plasma in TUMAN-3M [19]. First, the oscillations with a high frequency range – from 120 to 290 MHz, which is substantially higher than Ion Cyclotron Resonance frequency. Second, oscillations characterized by clear harmonic structure with up to 7 detectable harmonics and by lower range of fundamental harmonic frequency – 18-40 MHz.

2. Characterization of the emission in the range: 0.3-1.25 GHz

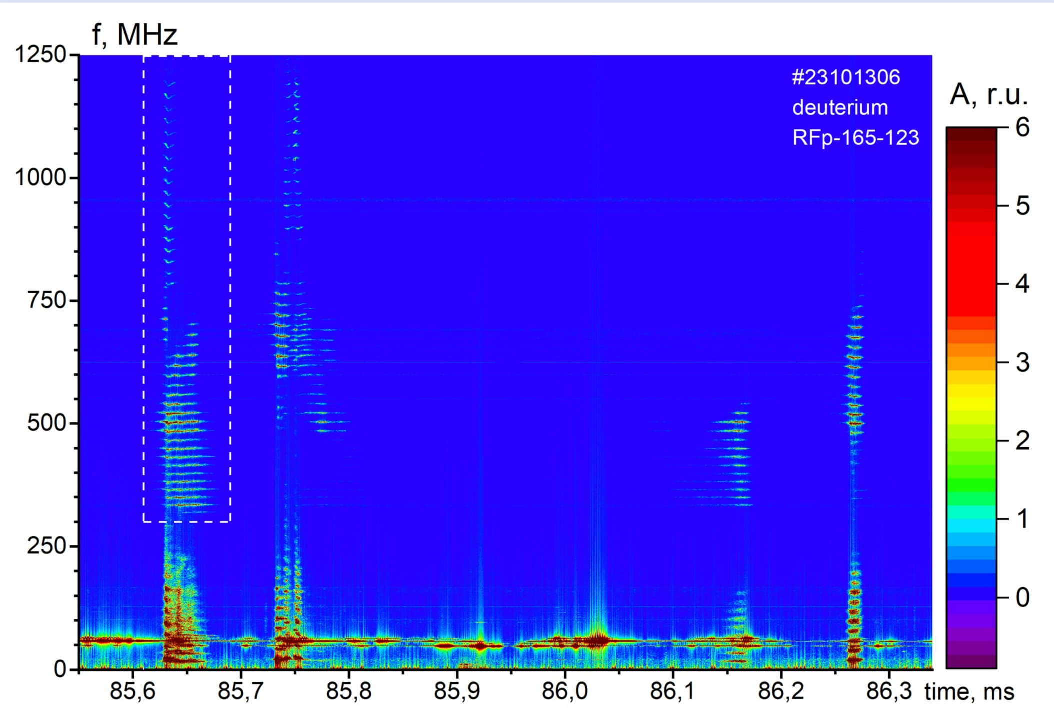

Fig.1. Spectrogram of magnetic oscillations measured in ohmic regime, $\bar{n}_e = 0.7 \cdot 10^{19}\ m^{-3}$, $B_t(0) = 0.8\ T$

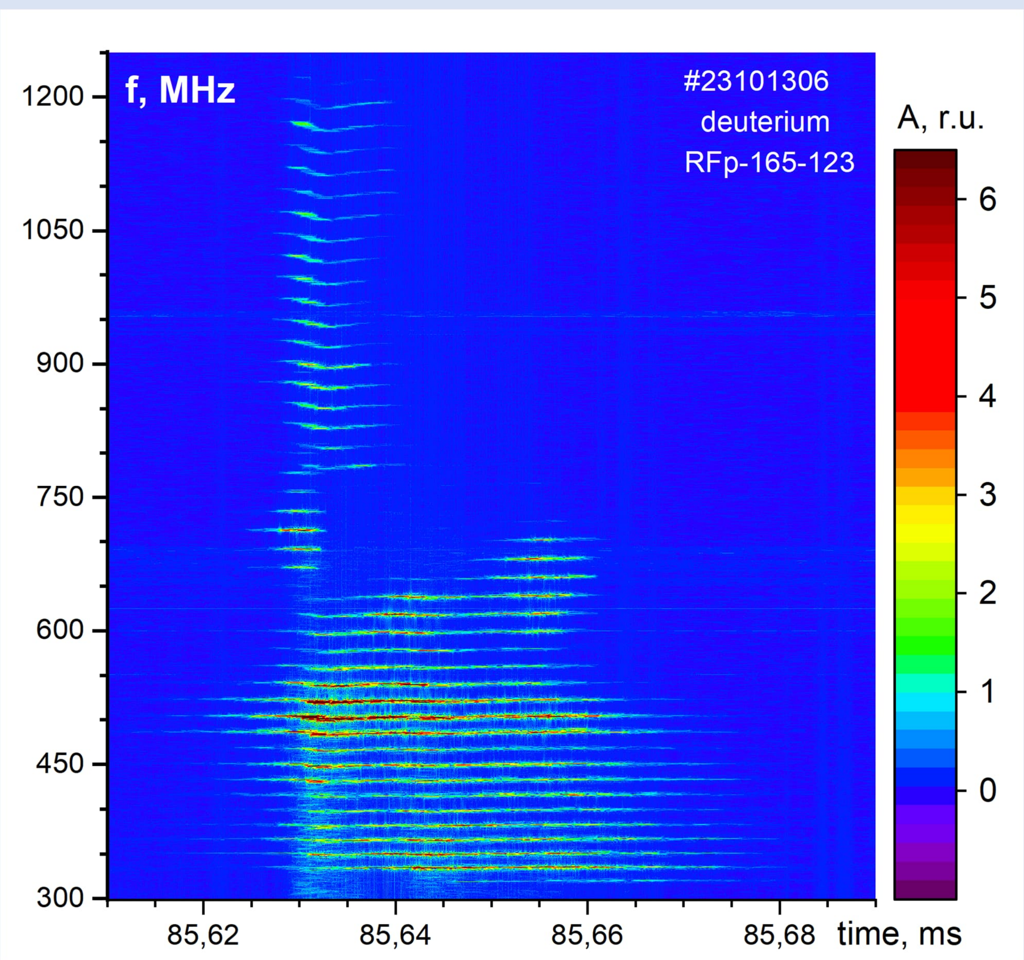

Fig.2. Enlarged spectrogram of magnetic oscillations shown in Fig.1

Magnetic oscillations have been measured using array of 16 magnetic probes sited on the internal surface of circular cross-section of the vacuum vessel [20].

Using ADC with sampling rate up to 2.5 GHz bursts of wide spectra oscillation have been detected in low density ohmic plasmas, see Figures 1, 2 & 3.

The bursts duration was in the range of 10-100 μs. In few cases, the bursts duration extended to 400 μs.

The highest frequency in the spectrum was close to $4\omega_{LH}$, and the minimum was $\sim 2\omega_{ci}$, where ω_{LH} is the Lower Hybrid frequency, ω_{ci} is the deuterium Ion Cyclotron Resonance frequency at the high magnetic field side of the torus.

Observed oscillations were identified as whistler waves.

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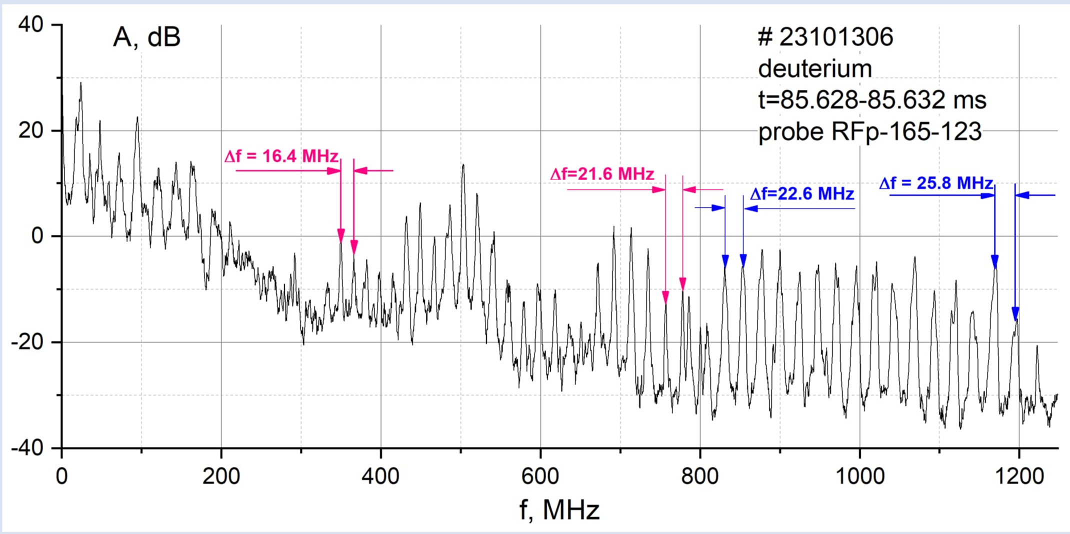

Fig.3. Spectrum obtained in shot shown in Figs.1&2. Frequency gap gradually increases with frequency.

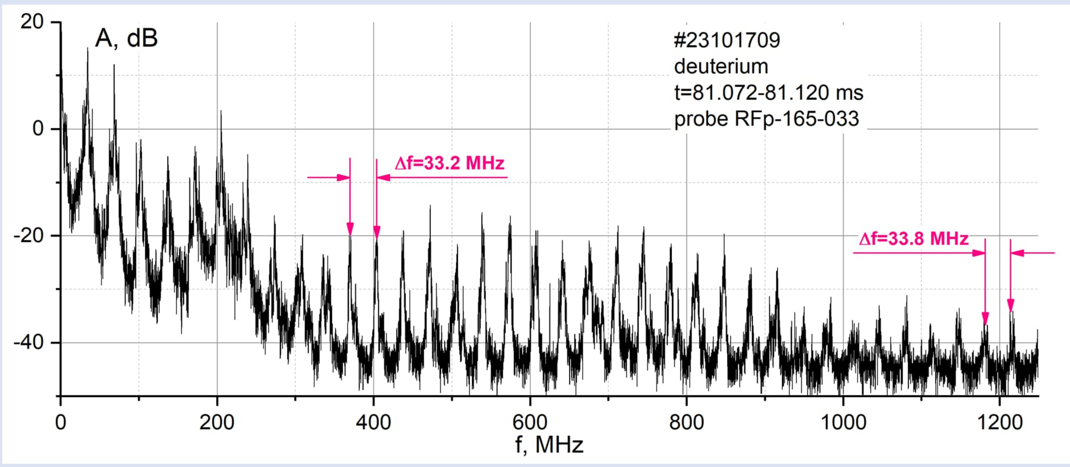

Fig.4. Spectrum of magnetic oscillations measured in shot with $\bar{n}_e = 0.8 \cdot 10^{19}\ m^{-3}$. Dependency of frequency gap on frequency is essentially weaker than in the shot with lower density (Fig. 3).

When density was increased to $0.8 \cdot 10^{19}\ m^{-3}$ the frequency gap became larger ~ 33-34 MHz and exhibit weak dependence on frequency, see Figures 4 & 5.

It should be noticed; that frequency gap increases with increasing toroidal magnetic field. Lowering the magnetic field in the shots #23101707 and #23101709 by factors of 0.91 and 0.89, respectively, resulted in the corresponding gap decreases by factors of 0.92 and 0.9.

Observed tendency indicates proportionality of the frequency gap to magnetic field, though scale of B_t variation in the experiment was limited. Typical magnitude of the frequency gap in the studied spectra varies from 15 to 40 MHz – the quantities, which are much higher than ω_{ci}.

This allows to conjecture that the observed features of the spectra are formed as a result of the existence of cavity resonances in tokamak vessel.

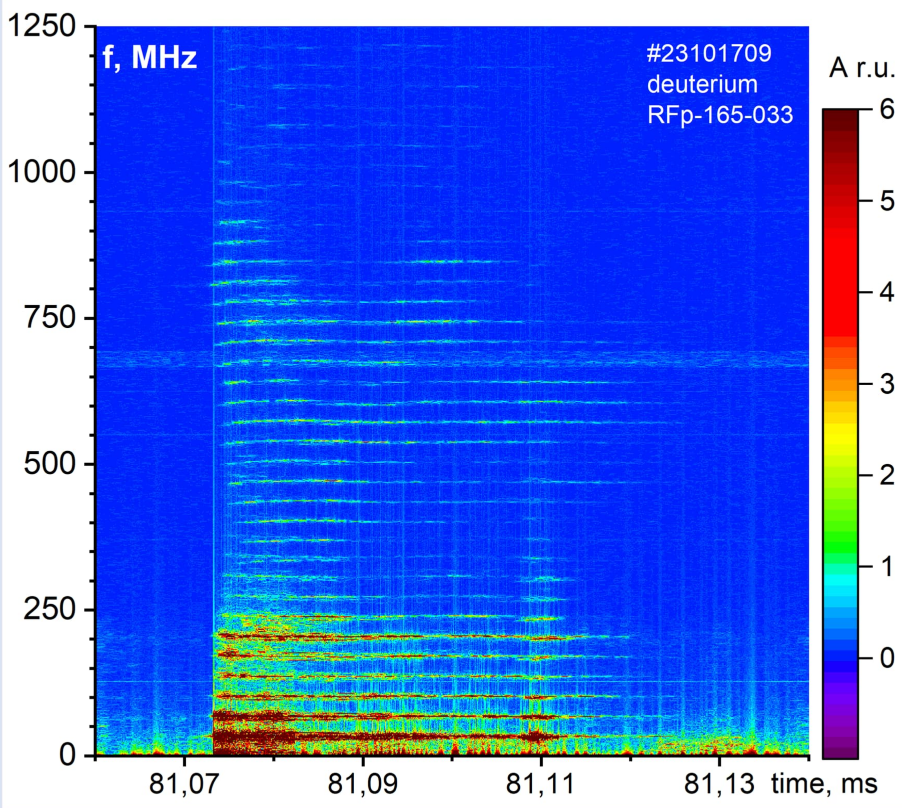

Fig.5. Spectrogram of oscillations measured in shot with $\bar{n}_e = 0.8 \cdot 10^{19}\ m^{-3}$.
In contrast to shot shown in Figs. 1&2 no separate frequency groups could be defined.

3. Estimations of RE E_{MAX} using Gamma-ray spectrometry

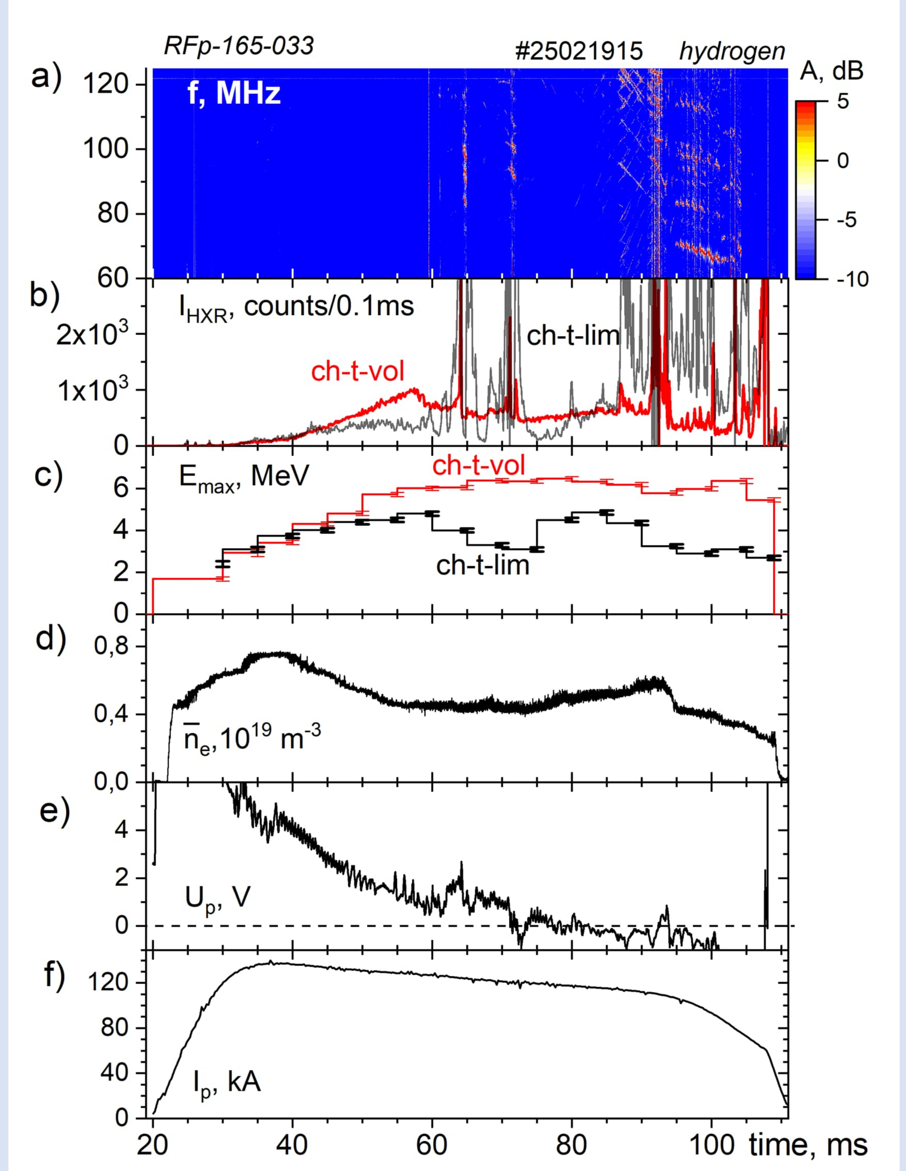

Fig.6. Bursts spectrogram recorded by 250MHz ADC in shot with $\bar{n}_e = 0.5 \cdot 10^{19} m^{-3}$ – a); γ-rate measured by tangentially viewing detectors – b); E_{max} of RE – c), density evolution – d); U_p – e); I_p – f).

Oscillation bursts correlate with spikes of gamma-ray flux in shots with low density. Spectrogram of the bursts and signal from γ-ray counter in shot with $\bar{n}_e = 0.5 \cdot 10^{19}\ m^{-3}$ are shown in Fig.6. Channel "ch-t-lim" acquired γ-quanta produced in tungsten limiter by RE slowing down. Channel "ch-t-vol" acquired quanta born mainly in plasma volume.

Simultaneous bursts on spectrogram – a), and spikes of γ-detectors signals – b), indicate a key role of the REs in bursts generation.

Calculation of E_{max} in RE spectrum using DeGaSum deconvolution code [21] is shown in frame c). Bursts appear when RE energy reaches 4-5 MeV.*

As it is seen in frame a) bursts of emission are damped when RE beam fall out of the plasma.

**Excess of E_{max} in channel "ch-t-vol" over E_{max} in channel "ch-t-lim" is likely due to an overload of electronics in the channel "ch-t-vol", which cannot be fixed during the experiment.*

ACKNOWLEDGEMENTS

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