OBSERVATION OF HIGH-FREQUENCY OSCILLATIONS IN THE TUMAN-3M OHMIC PLASMAS

S.V. LEBEDEV, G.I. ABDULLINA, L.G. ASKINAZI, YU.F. BARANOV, A.A. BELOKUROV, N.A. ZHUBR, V.A. KORNEV, D.V. RAZUMENKO, A.I. SMIRNOV, A.E. SHEVELEV, L.K. SHUVALOVA, A.S. TUKACHINSKY, E.M. KHILKEVITCH

Ioffe Institute, St Petersburg, Russian Federation

Email: sergei.lebedev@mail.ioffe.ru

In addition to the previously studied oscillations at the frequencies of the Alfven [1] and Ion Cyclotron [2,3] resonances, oscillations with higher frequencies of 120-300 MHz were found in the TUMAN-3M tokamak. The oscillations were interpreted as Whistler waves [4]. The use of ADCs with sampling rate of up to 3 GHz in the recent experiments made it possible to detect bursts of oscillations, which spectra extended to 1.2 GHz and higher, see Figure 1. The bursts of the high-frequency oscillations were observed in deuterium plasma with the average detected electron density $(0.5-0.8)\cdot 10^{19}\ m^{-3}$, toroidal magnetic field $0.9\ T$, plasma current $120\ kA$. The highest frequency in the spectrum is close to $4\omega_{LH}$, and the minimum is $\sim 2\omega_{ci}$, where ω_{LH} is the Lower Hybrid frequency, ω_{ci} is the deuterium Ion Cyclotron resonance frequency at the strong magnetic field side of the torus.

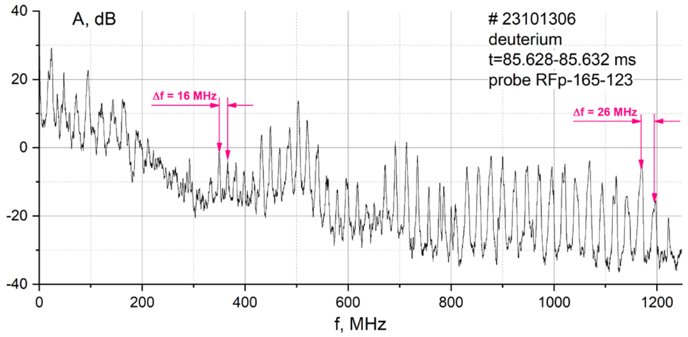

Fig.1. Spectrum of the high frequency oscillations at $\overline{n}_e = 0.5\cdot 10^{19}\ m^{-3}$ recorded by ADC with sampling rate of 2.5 GHz.

The shape of the bursts' spectra looks like a comb. At lower densities $(0.5-0.6)\cdot 10^{19}\ m^{-3}$ the frequency gap in the spectrum gradually increases with frequency. As seen in Fig.1 the gap increases from 16 MHz at 370 MHz to 26 MHz at 1.2 GHz. When density increases to $0.8\cdot 10^{19}\ m^{-3}$ the frequency gap became larger ~ 33-34 MHz and has a weak dependence on frequency, see Fig.2. It should be noted, the frequency gap increases with toroidal magnetic field. Lowering of 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 0.9 and 0.92. 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 suggest that the observed features of the spectra are formed as a result of the existence of cavity resonances in the tokamak vessel.

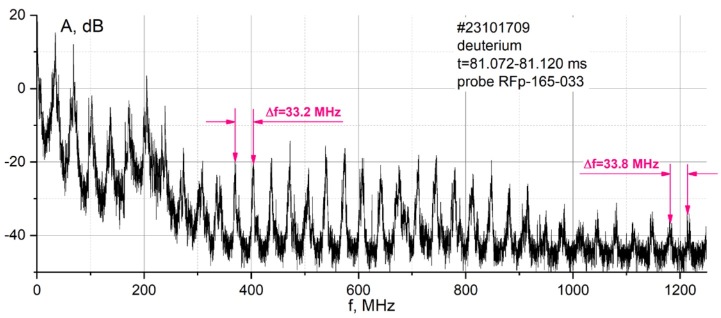

Fig.2. Spectrum of the high frequency oscillations at $\overline{n}_e = 0.8\cdot 10^{19}\ m^{-3}$ recorded by ADC with sampling rate of 2.5 GHz.

Duration of the bursts of high-frequency oscillations was in the range of 10-100 μs. In few cases, the bursts duration reached 0.4 ms. Typical pattern of the phenomenon could be seen in Fig.3. Although triggering mechanism of the bursts' appearance is not clear yet the presence of runaway electrons (REs) in plasma is certainly a necessary prerequisite. The oscillations appear when energy of REs reaches 4-5 MeV as it was found using DeGaSum deconvolution code [5] applied to gamma-ray spectra obtained with a help of tangentially directed HPGe gamma detector [6]. The bursts of oscillations are damped when RE beam fall out of the plasma.

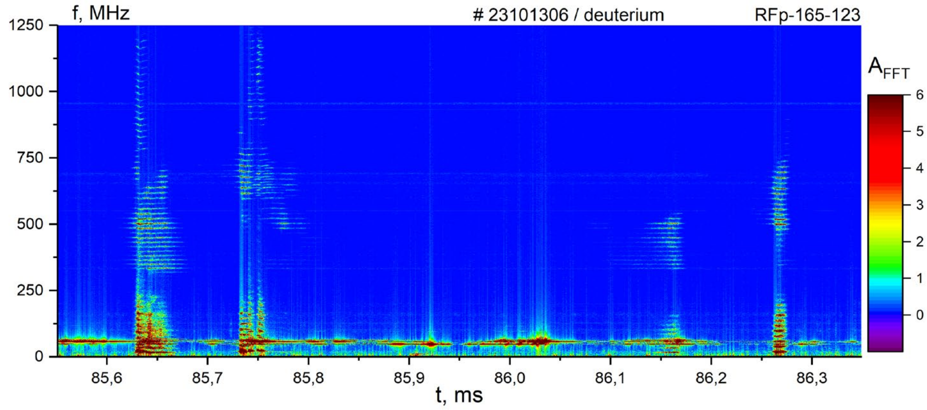

Fig.3 Spectrogram of a sequence of high frequency bursts observed in a shot with $\overline{n}_e = 0.67 \cdot 10^{19}\ m^{-3}$, $B_t(0) = 0.83\ T$.

Observed phenomena are of importance since the high-frequency plasma emission can be used for early detection of RE beams potentially dangerous for tokamak integrity [7]. In connection with the above-described experiments Whistler observations reported by DIII-D [8] should be mentioned. In those experiments Whistlers excited by RE appear as multiple discrete modes at frequencies below 200 MHz, though frequency gap is much smaller compared to what was observed our experiment. The modes' frequency follows Alfvenic dependence on magnetic field and exhibits weak dependence on density. Observations of emission driven by RE were reported by FTU [9] where ω close to ω_{LH} have been found. A clear wave frequency scaling with respect to the electron density was found. The scaling allowed an identification of the instabilities as lower hybrid waves. Spectra of oscillations in FTU contains few peaks, no comb structure was observed. In an ohmically heated plasma on the FT-2 tokamak intensive oscillations in the form of bursts in the LH frequency range of 0.2−1.0 GHz were found. Frequency gaps in the bursts' spectra are equal to IC resonance frequency [10], in contrast with observations presented in this report. RE driven instabilities may cause rapid growth of the perpendicular energy as it was found in the first tokamaks, so called "fan" instability [11]. No influence of the bursts on diamagnetic signal was found in our experiments, thus the fan instability cannot explain reported observations.

ACKNOWLEDGEMENTS

Routine operation of TUMAN-3M tokamak was supported by State order provided by RF Ministry of Science and Education, contract FFUG-0021-0001. Experiment on high-frequency bursts observation was supported by contract FFUG-2024-0028. Authors are grateful Dr. A.D. Gurchenko for offering high sampling rate ADCs.

REFERENCES

[1] LEBEDEV, ET AL, Alfven instabilities in hydrogen, deuterium and helium plasmas in ohmic regime of TUMAN-3M tokamak, Proc. 43rd EPS Conf. on Plasma Phys. EPS-2016 **40A** P5.036.

[2] LEBEDEV, ET AL, Observation of ion cyclotron emission from ohmically and NBI heated plasmas in TUMAN-3M tokamak, EPJ Web Conf. **149** (2017) 03010.

[3] ASKINAZI, L.G., ET AL, Ion cyclotron emission in NBI-heated plasmas in the TUMAN-3M tokamak, Nucl. Fusion **58** (2018) 082003.

[4] LEBEDEV, S.V., ET AL, First observation of whistler waves and ion cyclotron emission with a frequency ω higher than Ωci in the ohmically heated plasmas in the TUMAN-3M tokamak, Proc. 29th IAEA FEC2023 Conf. https://conferences.iaea.org/event/316/contributions/29281/attachments/15328/24690/Lebedev-EX-W.pdf.

[5] KHILKEVITCH, E.M., ET AL, Application of deconvolution methods to gamma-radiation spectra of thermonuclear plasma, Tech. Phys. Lett. **39** (2013) 63–67

[6] ILIASOVA, M.V., ET AL, Measurements of γ- and neutron-radiation spectra in nuclear reactions with ^{3}He and ^{9}Be ions, Tech. Phys. Lett. **47** 2 (2021) 103–106.

[7] HENDER, ET AL, Progress in the ITER physics basis, Nucl. Fusion **47** (2007) S128–202.

[8] SPONG, D.A., C., ET AL, Phys. Rev. Lett., First direct observation of runaway-electron-driven whistler waves in tokamaks, **120** (2018) 155002.

[9] BIN, W., ET AL, Phys. Rev. Lett., First intrashot observation of runaway-electron-driven instabilities at the lower-hybrid frequency range under ITER-relevant plasma-wave dispersion conditions, **129** (2022) 045002.

[10] DYACHENKO, V.V., ET AL, Tech. Phys., The lower hybrid frequency range wave emission in the ohmic discharge of the FT-2 tokamak **68** (2023) 5 587.

[11] VLASENKOV, V.S., The runaway electron discharge regime in the Tokamak-6 device, Nucl. Fusion **13** (1973) 509.