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WAVES GENERATED IN THE VICINITY OF THE XENON PLASMA GUN IN THE APEX-EXPERIMENT

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ABSTRACT

Wave and plasma observations were made in a close vicinity of a xenon gun, carried at altitudes near 500 km in the APEX-experiment. Wideband noise associated with neutral gas releases and steady beam currents were detected. In modulation regime even and odd harmonics of the beam modulation frequency were observed. A delay in wave emissions after modulated beam injection was terminated was also detected. This effect was accompanied by electron temperature and density disturbances as measured by a plasma density and temperature device.

INTRODUCTION

Active experiments with ions and neutral gas releases have a long history, beginning with launches of sounding rockets in the sixties. Their purpose included excitation of artificial aurora and stimulation of plasma turbulence in the ionosphere (Hess et al., 1971, Cambou et al., 1975, Winkler, 1980). In past active experiments significant progress has been made in the study of the generation of electrostatic and electromagnetic waves in the near zone of DC, modulated electron beams, and neutral releases (Shawhan et al., 1984, Neubert and Banks, 1992). Equidistant harmonics in the frequency range from 1 to 5 kHz in a near vicinity of sounding rocket during argon plasma gun operation were detected (Cahill et al., 1993). Slow variations of the spectrum and intensity of VLF-waves were detected in the process and after neutral xenon and nitrogen releases in the satellite "Active"-experiment (Bankov et al., 1993, Mikhailov et al., 1994). This paper presents observations of VLF wave stimulation in the near zone of the xenon plasma gun in the APEX-experiment.

DESCRIPTION OF THE EXPERIMENT

The satellite Intercosmos-25 (APEX-experiment, IC-25) had been launched on 18 December, 1991 into on orbit with apogee 3080 km, perigee 440 km and inclination 82.5°. The satellite attitude is known within an accuracy 1%. The IC-25 spacecraft carries a Xe neutral gas and plasma jet injection as well as scientific instruments for the measurement of the magnetic component of VLF waves (NVC-ONCH receiver) and the ion density (Dokoukin, 1992). Hundred second pulses of xenon injection with 2A current and 250 eV energy were realized in two regimes: (i) without modulation and (ii) with current modulation at frequencies 62, 125, 250, 500 and 1000 Hz with square-wave form. These regimes are referred to as

PDC for (i) and P62, P125, P250, P500 and P1000 for (ii). Pause between pulses takes place over a period of fifty seconds. The cycle of the gun operation involves the fire up stage, injection of a non-modulated beam, and subsequent injection of a modulated beam. More 70% of injected particles was ionized. The injection direction formed an angle 45° both with the direction from the Earth's center to the satellite and with the direction opposite to the satellite velocity. The density and temperature of plasma have been measured by the KM10 device (Dokoukin et al., 1992).

EXPERIMENTAL RESULTS

On the orbit 767 on 20.02.92 the plasma generator was operating with the modulation frequency 1000 Hz. Figure 1 presents spectra of the VLF magnetic field in the band up 4 kHz. On the vertical axis are given the jet generator current and the operating modes, abscissa: frequency, third coordinate is time in interval between 21.22:05–21.22:11 UT, curves are spectral power density of magnetic induction B in arbitrary units. Spacecraft coordinates are shown in Figure 3. In the considered interval, the following effects were observed: (i) the noise level increase in the non-modulated beam mode, (ii) P1000 - excitation of even and odd harmonics of modulation frequency of 1000 Hz. In Figure 2 are presented the dynamic spectra of VLF signals received on orbit 756 when the plasma jet generator operated with the modulation frequency 125 Hz. In this figure, one can see during the first 3 s the noise related to the gun operation in the DC mode. After the modulation is on, some harmonics of the modulation frequency are seen, the most intensive being the first, second and third ones. In Figure 3 results obtained on the orbit 767 are presented. Abscissa presents time and orbital parameters, ordinates (from bottom to top) show gun current I in A, electron temperature Te_X (K), where X is coordinate along the velocity of satellite, ion density in cm^{-3} and magnetic induction B in arbitrary units for filters at frequencies shown in the figure. In the considered interval there are two gun pulses.

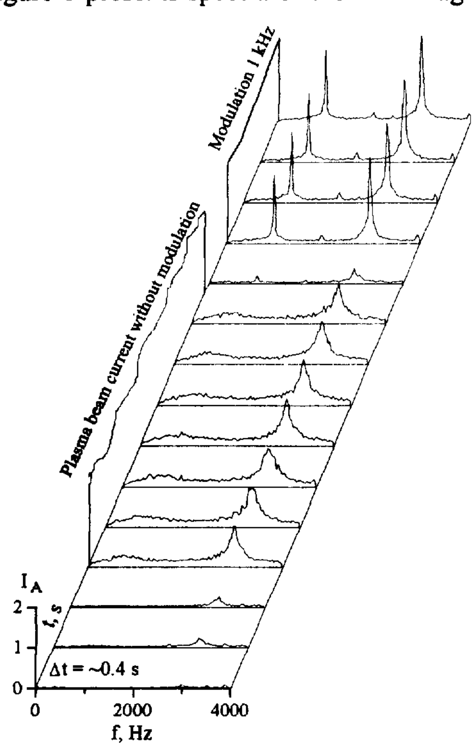


Fig. 1. Spectra of VLF-waves in different modes of Xe-gun operation

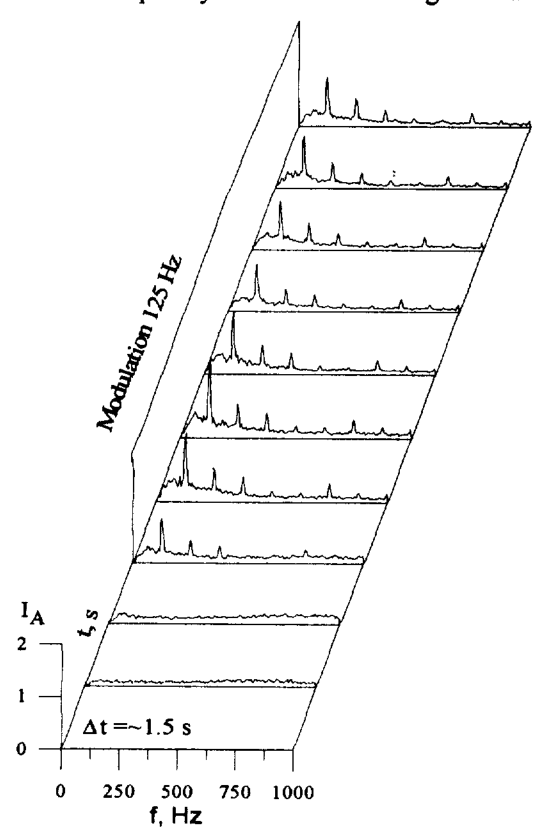
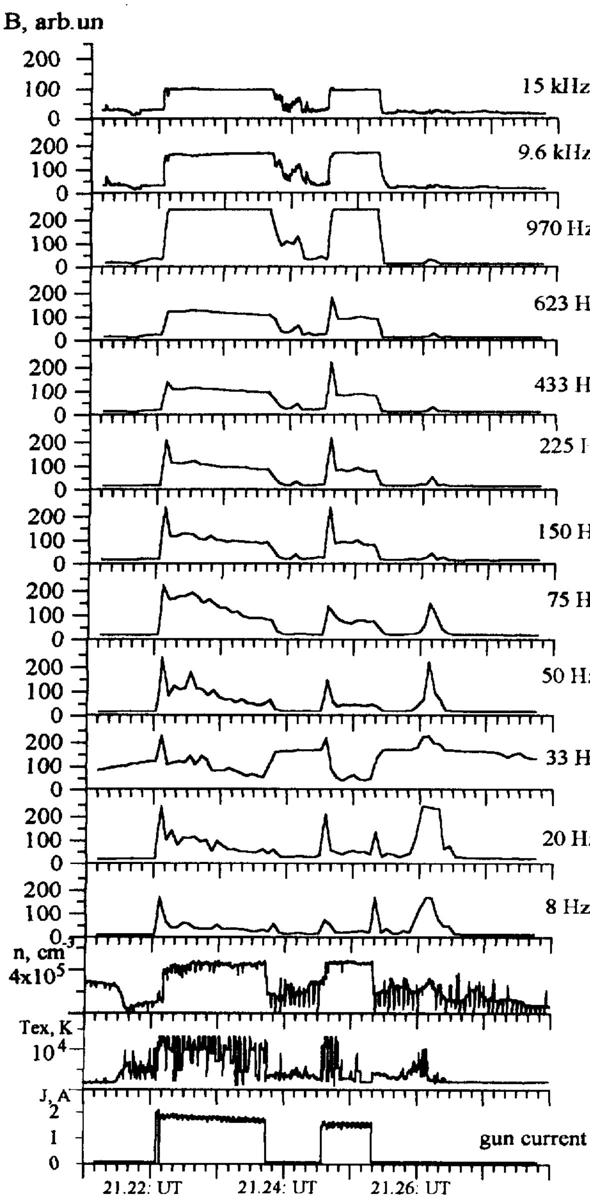


Fig. 2. Spectra of ELF-waves in P125 mode of Xe-gun operation on orbit 756 20.02.90. Time interval 21.02:03 – :18, coordinates: h=560 km, lat =48.2°N, long = 8.3°E.

During the first impulse an increase in the noise intensity up to maximum level of the receiving scale at frequency from 75 Hz to 15 kHz is detected. At frequencies from 8 to 75 Hz the noise level is about ¼ of the scale. Simultaneous increases of ion density and strong fluctuations of Te_X are registered. When the first pulse is off, the noise at frequencies 9.6 and 15.0 kHz remains and at the same time electron temperature fluctuations are detected. During this time oscillations with periods about 8 and 5 s on envelope curves $B_{9.6}$ and $B_{15.0}$ were detected. Spectral analysis with subtracting of line trend of $B_{9.6}$ and $B_{15.0}$ of envelope curves, which is presented in Figure 4, shows that noticeable peaks occur at frequencies 0.04-0.08 Hz and weaker ones at 0.125 and 0.17 Hz. According to Figure 3 the second pulse produces another reaction, namely significant increase in B_{970}, $B_{9.6}$ and $B_{15.0}$ filters without any delay after turning off the gun. In contrast to this at frequencies 8 to 75 Hz and in Te long lasting and intensive variations are observed. The peak B coincides with an electron temperature peak. It is possible that this is related to different nature of the excited wave in the different conditions of the ambient plasma. The interval between some elements of the pulses is about 130 s or near 1000 km. This can cause a significant change in the excitation conditions especially in the angle between the beam and magnetic field directions.



h, km	632	723	825
lat,°N	54.1	61.7	68.8
long,°E	33.8	37.0	42.1
L	2.636	3.886	6.078
MLT	0.19	0.71	1.39
SZA	136.2	129.0	122.1

Fig. 3. B_{VLF}, B_{ELF} in relative units, density of ions n, T_e and gun current I. Frequencies are indicated at the right of the Figure. Coordinates include h - height, MLT - magnitude local time and SZA - solar zenith angle.

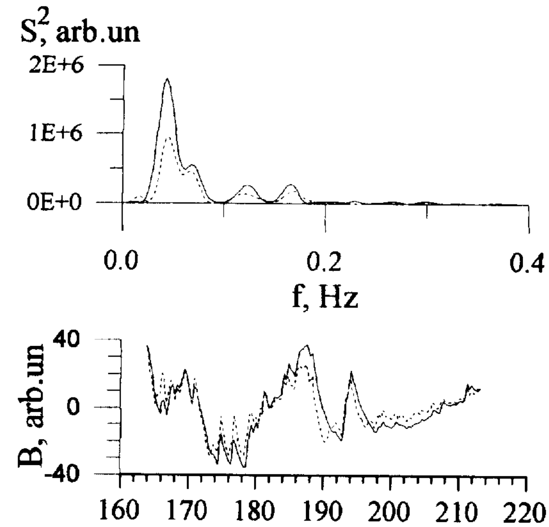


Fig. 4. Spectra of envelop curves for channels 9.6 and 15.0 kHz between Xe-gun pulses in interval 21.23:40 to 21.24:34.

DISCUSSION

Analysis of figures 1-4 results in the conclusion that both during and after the injection process a complicate picture is formed. It is suggested that during the injection time different wave modes are excited. Although the direction of injection is opposite to that of the satellite velocity, excited waves propagate along the magnetic field and some of them may travel in the same direction as the satellite velocity. The time of joint movement is defined by the wave packet dimensions. Using the law of charge conservation applied to the charge injected by Xe-gun, we may estimate the linear dimensions of the beam. The total charge equals $I \cdot t$, where t is the duration of the injection. This charge diffuses in a cylindrical volume $S \times l \times \Delta n$, where S and l are the cross section and length of beam respectively and Δn is the density above that of the ambient plasma. Such estimations, if we assume radius of beam 500 m (Volokitin and Drozdov, 1992), give a length of beam ~1 km. The relation between length of a beam and wave packet dimension must be given in future work. The time of joint movement equals $\Delta l/\Delta v$, where Δl is the projection of wave packet dimension on X-axis, and Δv is difference between velocities of wave and satellite along the same axis. The situation may be different in high latitudes where the Earth's magnetic field is near to vertical.

The total intensity of magnetic field in the near zone of about 1 nT is in agreement with Cahill's data for electric ~0,1 V/m, taking into account differences between the experiments (Cahill et al.,1993).Using theory of linear antennas in a plasma and that the field decreases as r^{-2} for VLF propagation perpendicular to magnetic field, we find, that the field in the far zone at a distance of ~250 km may be near $1.5.10^{-2}$ pT, which is at the limit of sensitivity of the receiver on subsatellite (Oraevsky et al.,1994) but is still detectable.

Observations of time delays are in agreement with theoretical calculations of impact-generated plasma clouds and excitation in these clouds of alfven waves (Volokitin and Drozdov,1992). The fundamental frequency of modulation, 0.17 Hz (figure 4) is near to 0.33 Hz, which coincides to the frequency of the magnetic energy density integral $(B^2/4\pi)$ dz variations, allowing for the approximate character of the estimations.

CONCLUSION

Wide range variations of spectra and amplitudes of waves in xenon gun operation time are introduced. These data give us an introduction to the dynamics of wave phenomena in near zone of the satellite and estimate the general picture of wave propagation in near and far zones during the xenon gun operation. The authors thank referees and Dr. Rietveld for comments.

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