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# Modeling of space plasma physics phenomena on large KROT plasma device

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## Abstract

Large KROT device is developed in IAP RAS for modeling of space plasma physics phenomena. The core of the facility is pulsed RF plasma source with MW power level. Well repeated and highly uniform plasma, magnetized or not, can be produced in a volume of several tens of cubic meters. An overview of the facility operational parameters is presented along with the results of recent experiments.

## 1. KROT device description

KROT plasma facility was constructed in the beginning of 1980s for model studies of space phenomena and interaction of superstrong microwaves with plasmas. Device represents a stainless steel vacuum chamber with the volume 180 m$^3$, which is evacuated down to the base air pressure $p = 3 \times 10^{-6}$ torr. Working gas (Ar, Ne, He, $H_2$) pressure is $p = 5 \times 10^{-5} \ldots 5 \times 10^{-3}$ torr. Plasma is produced via pulsed inductive RF discharge. Four paraphase vacuum tube RF generators are used for gas ionization and plasma heating (power 1 MW, operating frequency 5 MHz, pulse duration 0.2 … 2 ms). Loop antennas for plasma production are installed within a chamber. The discharge is pulsed ones per five, ten, or twenty seconds.

At a low pressure ($p < 5 \times 10^{-4}$ torr) the dimensions of nonmagnetized plasma are determined by the length and the diameter of the chamber working section, which are 10 m × 3m. Nonmagnetized plasma with density $n_e = 8 \times 10^{11}$ cm$^{-3}$ and electron temperature $T_e \sim 10$ eV can be produced in a volume of about 80 m$^3$. To magnetize the plasma, the solenoid is installed within a vacuum chamber, which generates the magnetic field of mirror configuration with trap ratio $R = 2.4$. To form a current pulse in the solenoid, the capacitor storage is used (5 kV, 86 mF) which stores energy of about 1 MJ. Magnetic field pulse duration is 20 ms, magnetic field strength in minimum is up to $B_0 = 1500$ G. The magnetized plasma of maximum density $n_e = 2 \times 10^{13}$ cm$^{-3}$ is produced mainly within the solenoid (4 m in length, 1.5 m in diameter) in a volume of about 10 m$^3$.

## 2. Experimental results

The paper contains a brief review of the recent experimental results. Large plasma column of the KROT device is ideally suited for studies of propagation of the waves in “boundary-free” conditions, similar to those in near-Earth plasma environment. We focus on whistler mode waves, which play an important role in many magnetospheric and ionospheric processes, including the transfer of the electromagnetic energy in ELF and VLF bands, generation of natural emissions, precipitation of energetic electrons from radiation belts.

First, model studies are performed on whistler waves’ propagation in elongated irregularities (ducts), generated in quasiuniform background magnetoplasma. In magnetosphere, sporadic ducts are responsible for guided field-aligned propagation of natural and man-made whistlers. In ionosphere, artificial density ducts can occur due to the operation of heating facilities. Since the refractive index of whistler mode waves depends both on plasma density and ambient magnetic field strength, the density and magnetic field “duct-like” irregularities can strongly affect the propagation of whistlers. Detailed laboratory results on whistler wave trapping and propagation in ducts can be find in [1], [2], [3].

Second, the experiments are performed, in which the parametric modulation of whistlers in plasma with time-varying parameters is studied. The modulation of the amplitude and the spectrum of whistlers by low-frequency plasma disturbances represents an effect, which is observed in near-Earth plasmas both for noise-like and discrete natural emissions. One of the possible modulation mechanisms is adiabatic (non-resonant) conversion of the amplitude and frequency of the radiation, which propagates in plasma with time-varying density or magnetic field. Primarily we consider the magnetic perturbations, since the magnetic field is less “sluggish” than the plasma density, and even strong variations of the magnetic field in Earth magnetosphere are not always accompanied by the density disturbances. In laboratory experiment, described in [4], [6], whistler mode waves are injected into plasma with periodic magnetic disturbances. During its propagation, whistler mode wave, which is initially monochromatic, undergoes the modulation of its amplitude and frequency with the period of the magnetic field variations. Relative frequency shift is as large as relative magnetic disturbance, $\Delta f/f_0 \sim \Delta B/B_0$. The amplitude modulation is also observed, which is due to strong group velocity dispersion of whistlers. It is remarkable that similar modulation mechanism can be responsible for the formation of structured Pc1 band magnetic pulsations, representing the ion-cyclotron waves, or “ionic whistlers”.

Third, the generation of dc and low frequency magnetic disturbances by intense whistler mode waves is studied on KROT device. In a weakly collisional plasma, quasistationary (dc) currents can be excited by a ponderomotive force. In a magnetoplasma, potential ponderomotive force is capable of exciting the solenoidal dc currents, which have been recently discovered in experiments [5]. If the whistler-band pump represents a narrow beam parallel to ambient magnetic field, dc currents enclose the pump beam, and produce axial magnetic disturbances. Solenoidal currents are due to the azimuthal drift of electrons, initiated by the transverse ponderomotive force crossed with the background magnetic field. Magnetic disturbances are mainly of the paramagnetic type. If the pump intensity is modulated, excitation of low-frequency currents and magnetic fields at the modulation frequency is possible. Nonlinear drift currents form a “wireless” antenna, which can radiate low frequency waves to surrounding plasma.

## 3. Summary

Large plasma devices enable the performance of the model studies of the waves in space plasma environment. The propagation effects of low frequency plasma modes, like whistler or Alfven waves, can be investigated only on large devices, since their wavelengths are too large for typical laboratory plasma parameters. A number of ionospheric and magnetospheric effects, which are significant for these waves, can be reproduced in laboratory.

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