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SPATIAL AND TEMPORAL CORRELATIONS OF ELECTRIC FIELDS IN A WEAKLY TURBULENT PLASMA

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Experimental investigations of processes of transition of a plasma into a turbulent state and of stationary turbulence are of interest to plasma physics and to various applications. These processes can be investigated by using as an example the simplest and most prevalent two-stream instability.

The most important characteristic of the turbulent state is the spectral energy density E_k^2 of the electric field.

The purpose of the present work was to determine this density by measuring the spatial autocorrelation functions of the electric fields of high-frequency oscillations excited in a plasma-beam discharge.

As is well known, development of two-stream instability is accompanied by strong heating of the plasma electrons and ions and by acceleration of an appreciable number of electrons to energies greatly exceeding the energy of the beam electrons. Apparently, the stochastic-acceleration mechanism is in operation [1-3] under these conditions. To check on this assumption it is necessary to determine the degree of stochasticity of the oscillations, and to measure the length and time of correlation of the electric fields, which determine to a considerable degree the effectiveness of the stochastic acceleration. Measurements of this type make it possible to establish the extent to which the "random phase" approximation [4], used in contemporary nonlinear theories of waveguide and oscillatory properties of plasma, is applicable under the experimental conditions. We have therefore also measured the correlation times of the electric fields and the temporal autocorrelation function.

The experiment was carried out with an electron beam with energy up to 5 keV and current 20 - 100 mA, in a magnetic field up to 2,000 G and at 10^{-4} mm Hg pressure. Under these conditions, a plasma is produced with density up to 6×10^{11} el/cm^2. With the aid of a cylindrical cavity placed ahead of the interaction chamber, the beam could be modulated at a frequency of 3,000 MHz (Fig. 1).

The spatial autocorrelation function $R(l)$ was determined by summing oscillations (600

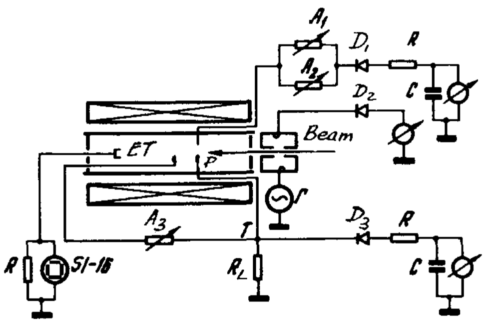

Fig. 1. Measurement scheme

- 6000 MHz) received at different points of the discharge in a quadratic detector, with subsequent time averaging

$$\langle R(\ell)\rangle_t = 2 \sum_k |E_k|^2 (1 + \exp(-ik\ell)),$$

where ℓ is the distance between probes. An important condition when plotting the autocorrelation function curves is that the frequencies of the measured oscillations lie in the region of the characteristic frequencies of the plasma. From the form of the function $\langle R(\ell)\rangle_t$ we can estimate the correlation length, and by using the relation

$$S_k = |E_k|^2 = \frac{1}{4\pi}\int_{-\infty}^{+\infty} R(\ell)\exp(ik\ell)\,d\ell - \int_{-\infty}^{+\infty} R(\ell)\,d\ell$$

we can also estimate the spectral energy density of the electric field.

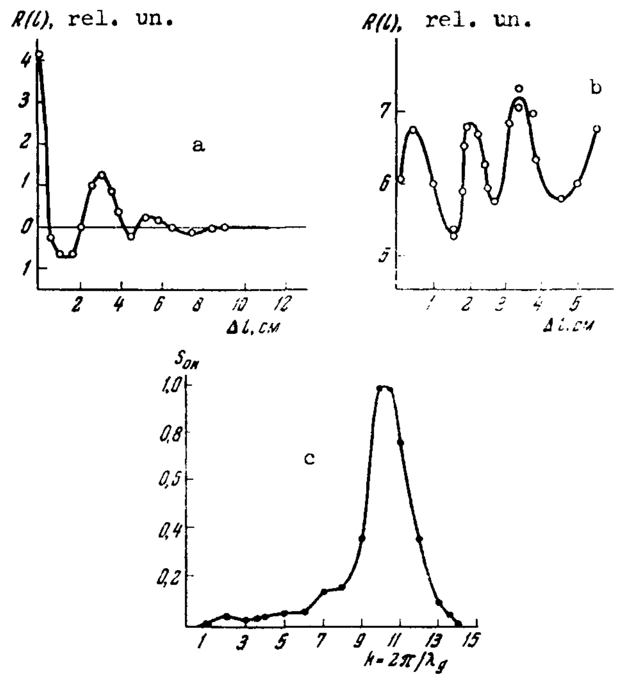

Fig. 2. Spatial autocorrelation functions of the oscillations and spectral energy density of the electric field

Figure 2a shows the autocorrelation function for the case of maximum amplitude of the excited oscillations. It follows from Fig. 2a that the high-frequency oscillations correlate over a length of 8 cm, i.e., a distance of 8 - 10 wavelengths. With decreasing amplitude, the oscillations change from stochastic to regular. This is clearly seen from Fig. 2b, which shows the correlation function $R(\ell)$ for oscillations with one-tenth the amplitude as under the conditions of Fig. 2a.

A similar curve is obtained also in the case when external modulation is superimposed on the beam. This confirms the assumption that external modulation leads to a narrowing of the wave-number spectrum and to a transition from stochastic into regular oscillations.

Figure 2c shows the spectral energy density E_k^2 of the electric field for the function $R(\ell)$ of Fig. 2a. The experimentally determined plot of E_k^2 is close to that calculated from the quasilinear theory in the paper by V. D. Shapiro [4]. The spectral-density curve shows a shift of the maximum from the expected k = 8 to the region k = 10 - 11. In all probability, this is connected with the fact that the beam loses part of its energy, as a result of which

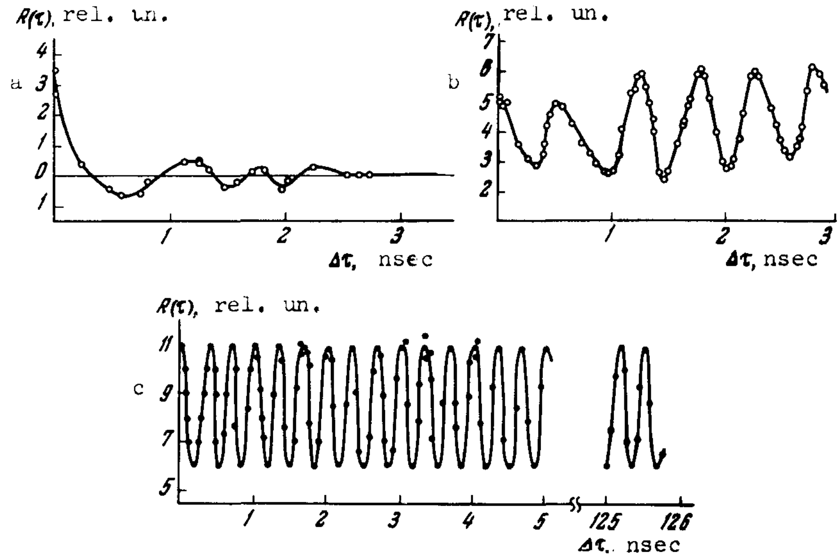

Fig. 3. Temporal autocorrelation functions of the oscillations

its velocities, together with the phase velocities of the wave, decrease.

Figures 3a - c show the temporal autocorrelation functions of the electric fields. To determine these, a high-frequency signal, received by an antemma, is split in half and passed through two coaxial lines of different length. The time delay of the signals is set by varying the relative length of the lines. The amplitudes of the signals are maintained equal with the aid of attenuators. The time-shifted signals are summed in a quadratic detector and are then integrated with an RC network (RC = 0.1 - 2). Thus, the output of the circuit is a signal equal to

$$u_\tau \simeq \langle f(t)f(t+\tau)\rangle = R(\tau),$$

where $R(\tau)$ is the temporal autocorrelation function of the signal.

Figure 3a shows the function $R(\tau)$ under the maximum-amplitude conditions, when intense 20-keV x-radiation is observed from the interaction region of the beam. The autocorrelation function has an aperiodic damped form, thus indicating the stochastic character of the oscillations. The correlation time is 3 nsec, i.e., of the order of ten oscillations. The decrease in the amplitude of the oscillations (attained by changing the pressure in the interaction region of the beam) leads to a strong change of the autocorrelation function. At small signal amplitudes it has the character of a periodic undamped curve (Fig. 3b). A similar character is possessed by the temporal autocorrelation function also under conditions when the beam is externally modulated (Fig. 3c), i.e., the oscillations have a regular character both at small amplitude and with external modulation.

Thus, investigations of the oscillations of a plasma-beam discharge by the correlation method have shown them to have an irregular stochastic character. The correlation length and correlation time depend essentially on the oscillation amplitude. A decrease in the oscillation amplitude, as well as external modulation, leads to an increase in the length and time of the correlation and to a transition from irregular to regular oscillations.

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NEW METHOD OF INVESTIGATING THE MECHANISM OF NUCLEAR INTERACTIONS

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An analysis of inelastic interactions at high energies, relative to the square of the 4-momentum transferred to the different groups of particles, in conjunction with an additional analysis of the effective masses of these groups, is the basis of a method proposed by one of the authors (Dremin) for the interpretation of individual events, i.e., for the separation of central and peripheral interactions, for the investigation of different types of the latter, and for setting a suitable Feynman diagram in correspondence with each event.

The squares of the transferred 4-momenta k^2 are determined by the formula

$$k_n^2 = (\hat{P}_1 - \sum_{i=1}^{n} \hat{p}_i)^2 = (\hat{P}_2 - \sum_{j=n+1}^{N} \hat{p}_j)^2, \qquad (1)$$

where $\hat{P}_1$, $\hat{P}_2$, $\hat{p}_i$, and $\hat{p}_j$ are the 4-momenta of the incident and resting nucleons and of the particles of groups i and j in the final state. The final particles are numbered such that 1 denotes the scattered nucleon, N the recoil nucleon, and the pions are numbered from 2 to N - 1 in increasing order of their c.m.s. angles.

We write

$$k^2 = f_- f_+ + |k_\perp|^2, \qquad (2)$$