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SIMULTANEOUS MEASUREMENT OF ELECTRIC FIELD AND ELECTRON DENSITY FLUCTUATIONS IN MAGNETIZED PLASMA BY MEANS OF ATOMIC/MOLECULAR BEAM OF HYDROGEN ISOTOPES

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This paper presents a method of electric field and electron density (or magnetic field) and their fluctuations simultaneous measurement. Radial transport induced by the low frequency fluctuations is now an important research subject in magnetically confined plasmas. Knowledge of $\tilde{E}_\theta$, $(\tilde{n}/n_e)^2$ and local cross-correlation between them are critical to understanding of the anomalous transport phenomena associated with instabilities or with the L/H transition.

An atomic/molecular beam of hydrogen isotopes (H_2^0 and D^0) is injected with velocity $v_0 \equiv \sqrt{2\mathcal{E}_0/M}$ along a chord into magnetized plasma column. The beam energy $\mathcal{E}_0$ is assumed to be $15 \div 60\ keV$ in the context of this paper. Part of the atoms and molecules are ionized and trapped. Then a small fraction of the trapped atomic ions D^+ makes a charge exchange collision on neutral particles when crossing the field of view of collinear analysers while the basic part of molecular ions H_2^+ is dissociated by the plasma electrons with rate coefficient $< \sigma_e v_e >$ and hits the analysers as the half-energy atoms. The line of sight of the analysers is approximately normal to the chord of injection. From comparison of the intensities $I_\leftarrow$ and $I_\rightarrow$ of full- and half-energy isotopes and of the energies $\mathcal{E}_\leftarrow$ and $\mathcal{E}_\rightarrow$ of half-energy isotopes H^0 emitted in opposite ($\leftrightarrow$) directions one obtains the simultaneous values of the electron density (or larmor radius ρ of the probe particles and hence the transverse magnetic field fluctuations)

$$n_e \approx \frac{v_0}{\pi\rho < \sigma_e v_e >} \cdot \ln\left(\frac{I_\rightarrow^{H^0}}{I_\rightarrow^{D^0}} \cdot \frac{I_\leftarrow^{D^0}}{I_\leftarrow^{H^0}}\right)$$

and of the electric field

$$E_\theta \approx \frac{\mathcal{E}_\leftarrow - \mathcal{E}_\rightarrow}{e\rho}$$

at the crossing point of diagnostic beam and the line of sight of the analysers. The time resolution is of the order of $1\ \mu s$, the accuracy of $\tilde{n}/n_e$ determination is better than 10 % and the sensitivity of $\tilde{E}_\theta$ measurement is about of $10\ V/cm$.

Some results of this technique using on the mirror fusion experiment AMBAL-M are presented. A flutelike electric field $\tilde{E}_\theta$ and density fluctuations with a frequency near the $E_r \times B_z$ rotation frequency is observed. Local cross-correlation between $\tilde{n}$ and $\tilde{E}_\theta$ indicates large outward radial particle transport similar to predictions of the low frequency turbulence model.

[1] A.A.Kabantsev. Report INP 94-35, Institute of Nuclear Physics, Novosibirsk(1994) – in Russian.

Observation of Short-Wavelength Ion-Acoustic Waves Accompanying Strong Langmuir Turbulence in a Magnetized Plasma

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A continuation of the experimental study of developed strong Langmuir turbulence (DLT) driven by an electron beam [1] is presented. The main feature of DLT regime is that the spatial and temporal scales of the turbulent region far exceed the life-time and the dimension of a single caviton. An analysis of k-spectra of DLT in magnetized plasma shows that DLT in our experiments is well above the threshold of modulational instability for transverse low-frequency perturbations. The described experiments are devoted to search for ion-acoustic waves which may be generated by collapsing cavitons. The spectral range of the observation is dictated by the spatial scale where the generation rate is maximal. We have chosen it near $k \sim 0.1 \div 0.2 r_D^{-1}$ where the collapse should arrest.

The experimental conditions are as follows. The electron beam (700 keV, 2÷3 kA, 2 cm diameter, 200 ns) is injected into preliminary hydrogen plasma with the density $n_e \approx 10^{15} cm^{-3}$ and the electron temperature $T_e \approx 1$ eV. The plasma is created in a longitudinal magnetic field of mirror configuration with 4.5 T in the end mirrors and 2.5 T in the homogeneous part. The electron temperature reaches 50 eV after 40 ns from the beginning of the injection and then the plasma is non-isothermal with $T_e >> T_i$ during the REB pulse. The 10 J TEA laser with a variable pulse length (70 - 2000 ns) is used. The scheme with a direct detection of scattered radiation spectra is applied. The choice of the scattering angle (14^{o}) is determined by the spectral range of interest.

The frequency spectrum of the scattered radiation is studied by means of the grating based spectrometer. The ammonia absorbing cell was used for more detailed study of the scattered light spectra. In the spectral range used the power of scattered radiation is much higher than that produced by Langmuir waves. The frequency shift of the scattered radiation can be estimated at 2 GHz. For our experimental conditions the frequency of the ion-acoustic waves determined by the dispersion law is ν_s=1.6 GHz. That is in agreement with such estimation. The measured spectral energy density of low frequency oscillations is $W_{\mathbf{k}} / T_e = 6 \cdot 10^6$. An outline of the spatial spectrum of ion-acoustic turbulence is presented.

1. L.N.Vyacheslavov, V.S.Burmasov, I. V. Kandaurov, E. P. Kruglyakov, O. I. Meshkov, and A. L. Sanin, Bull. Am. Phys. Soc., v.**39**, No.7, p.1693 (1994).

Plasma Equilibrium at Intense Injection of Neutral Beams

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The injection of atomic beams into relatively cold dense target plasma may under certain circumstances affect the plasma equilibrium configuration. The source of this effect is non-potential part of the force acting on the plasma by atoms trapped in it. When the neutrals are trapped by atomic processes their mechanical momentum is transferred to the plasma. The additional force arising due to the absorption of the neutral atoms is very small in comparison with the pressure gradient; that is why it is usually neglected in the problem of plasma equilibrium thought can play significant role in the problem of plasma stability as was first noted by D.D. Ryutov in 1983.

The equation for the shape of magnetic surfaces in an open confinement system is obtained. It is shown that appreciable distortion of magnetic surfaces can occur if non-potential part of additional force is as small as p/R where p is the plasma pressure and R is the curvature of magnetic field lines.

To reduction of the magnetic surfaces distortions in axisymmetric open confinement systems efficiently promotes symmetrization of the atomic injection on azimuthal angle with the number of injectors increased. The dependence of the distortion upon the number of injectors is found and the role of fluctuations of injectors' parameters and their misplacement are elucidated. It is stressed that the infringement of axial symmetry of magnetic surfaces results in the occurrence of neoclassical transverse transport processes in the plasma.

Analytical theory is supported by numerical simulation of plasma configuration in Gas-Dynamic Trap and AMBAL tandem mirror operating at the Budker Institute of Nuclear Physics.

Radial Distribution of Sloshing Ions in GDT

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The GDT (Gas Dynamic Trap) is an axisymmetric mirror device, and the experiments with GDT facility have been in progress at Budker Institute of Nuclear Physics. Since the physical understanding of the experimental data in GDT is important not only for GDT, but also for application of the sloshing ions to any other concepts.

The sloshing ions are produced by oblique injection of a high energy neutral beam into a mirror confined plasma. In the GDT experiment, measurements of the sloshing ions has been carried out, and paticularly, the distribution function of the sloshing ions, average energy, density at the midplane and at the turning points, charge-exchange loss and the radial profile of plasma parameters have been obtained.

In the present paper, we carried out the Fokker-Planck simulation of the sloshing ions in GDT. The effect of the radial losses of the sloshing ions due to the radial drift is included in addition to the velocity space diffusion in the simulation. The drift is caused by radial inhomogenity of the plasma parameters. The time evolution of the distribution function of the sloshing ions function as velocity, pitch angle, radial coordinate is obtained. The radial distributions of the average density and the average energy of the sloshing ions are also calculated. These results are compared with the experimental data of the sloshing ions.

Comparison studies of different axisymmetric MHD-anchors in GDT experiment.

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The GDT (Gas Dynamic Trap) experiment consists of an axisymmetric 7m central cell and two outboard MHD-anchors attached from both ends through the linking magnetic mirrors. A distinctive feature of GDT is that the plasma confined in the central cell is strongly collisional, i.e. the ion mean free path of scattering into the loss cone is small compared to mirror-to-mirror distance. In GDT, the rate, at which the central cell plasma leaks out from the ends, is high enough in order to sustain relatively dense plasma in the stabilizing cells with the favorable curvature of the field lines. The stabilizing cells of two different types were tested experimentally: an expander end-cell with monotonically dicreasing magnetic field and a cusp end-cell. The comparison of the averaged pressure-weighted curvature of both anchors was made for the regimes with 15kV neutral beam injection. Injected power was varied up to 4MW. During the injection pulse, the population of the fast sloshing ions with mean energy of 7-8keV was produced giving destabilizing contribution to the pressure-weighted curvature. At certain moment, this caused the transition through the MHD stability boundary that resulted in increased plasma losses. We evaluated the stabilizing contribution of the anchors using the energy contents of the sloshing ions (W_f) and target plasma (W_p) measured at the stability boundary (see Fig.1,2).

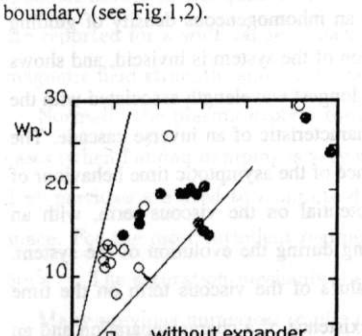

Fig.1 Plasma and sloshing ions energy contents at stability boundary

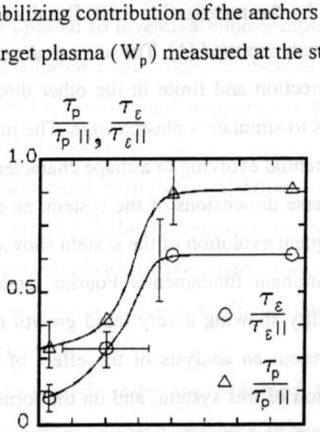

Fig.2 Plasma lifetimes vs safety factor with the cusp end-cell

The stabilizing property of the anchors was quantified using a safety factor Qs which was defined as absolute value of the ratio of the averaged pressure-weighted curvature in anchor and that in the central cell. Fig. 2 shows plasma lifetimes of particles and energy as functions of safety factor calculated from experimentally measured plasma parameters in the case of the cusp end-cell. The data was found to be in reasonable agreement with theoretical predictions based on Kruskal-Oberman energy principle for the large scale flute modes. Somewhat reduced value of the measured safety factor for the expander end-cell was noted.