P2 . 039

Ballistic Bunching of Fast Ions in a Mirror Trap

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The fast ions produced inside a mirror trap by neutral beam injection could form periodic short-lived density peaks near a turning point if the injection energy is properly modulated in time. Parameters of these density peaks depend on the energy modulation law, energy and angular spreads of the injector, scattering of bunched ions on the background plasma, and some other factors.

The most fundamental limitation on the peak bunch density is imposed by the own energy spread of the bunched ions. For the neutron source based on the gas-dynamic trap (GDT) [1], this constraint allows to increase the peak ion density 1.2-1.5 times. The shorter is the modulation period, the greater is the density peaking.

Another serious restriction on the bunch density can appear because of the angular spread (initial or acquired) of the bunched particles. However, this restriction can be avoided by the special choice of magnetic field profile, for which particle bounce-periods are independent on pitch-angles.

For practical applications of the ballistic bunching, the bunch should appear at all field lines simultaneously and at the same cross-section of the trap. The criterion of identical behaviour of particles on different field lines is derived. This criterion is easy to meet if the plasma pressure inside the trap is much less than the magnetic field pressure.

With the ballistic bunching, it is possible to produce controllable short bursts of the neutron flux in the GDT-based neutron source. However, the bunching has no effect on the average neutron yield because of the short duration of neutron bursts. The modulation of the neutron flux could significantly extend the field of application for the neutron source. Also, the bunching could serve as a precise plasma diagnostics in mirror traps.

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P1 . 057

Diagnostics for Measurement of High β Plasma Parameters in the Gas Dynamic Trap.

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New diagnostics based on neutral beam injectors of DINA type were installed on the GDT-device in Budker Institute of Nuclear Physics (Novosibirsk, Russia) for measurement of high-β plasma parameters. The Gas Dynamic Trap (GDT) is an axisymmetric mirror device with the high mirror ratio for confinement of collisional plasma with hot ion minority. Hot ions are produced in the trap by injection of high-power NBs into the collisional target plasma [1].

The presented diagnostics are the following:

1. Charge-exchange energy analyzer combined with beam produced artificial target for local measurements of angular and energy distribution functions of hot ions. The 100 μs, focused neutral beam of 15 keV energy (current density up to 1 A/cm^2) is injected at the GDT midplane and produces a local target for charge-exchange of fast ions. The energy of produced fast neutrals is measured by multichannel energy analyzer, that may observe the particle energy in rang of 2-20 keV.
2. The multichannel system for measurement plasma density profile. It is based on the neutral D-beam with energy of 25 keV and total equivalent current up to 2 A which is injected to plasma perpendicularly to magnetic field lines. The beam is attenuated 2-3 times, producing secondary D^+ ions which are registered by the multichannel detector installed outside the plasma. The ions, that has born in various points of the plasma column along a beam line, get in various channels of the analyzer. The amplitude of a signal in a channel depend on a local plasma density in the appropriate point, that allows to restore a density profile along a beam.

The date obtained by this diagnostics are using for the study of a high-β multicomponent plasma in GDT. The developed diagnostic equipment may be used in other type of magnetic trap.

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Dissipation structure of strong Langmuir turbulence in a non-Maxwellian plasma

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Strong Langmuir turbulence (SLT) is studied experimentally under conditions, which usually present problems for theory and numerical simulations. Among previously observed the distinctive features of SLT are relatively high level of turbulence (W/n_eT_e =0.25) and a large amount of superthermal electrons with the mean energy E_h = 10-20 T_e and $n_hE_h > n_eT_e$. Evidence of the occurrence of the Langmuir wave collapse under these conditions was found recently experimentally *). An estimation shows that the superthermal electrons increase the spatial scale of the collapse arrest to 100-150r_D in contrast to 20r_D for Maxwellian plasmas. Relativistic electron beam drives turbulence at about 800r_D and Langmuir oscillations with the adjacent spatial scales content the bulk of the energy of turbulence. To inspect a plasma microstructure in the above mentioned spatial range a multichannel IR laser scattering system has been developed and employed in experiments. Results obtained with this diagnostics, which enables observation of density depletions larger than 100r_D, are presented in the report.

Another peculiarity of SLT under investigation is the weak dumping of ion-acoustic waves (Te >> Ti) and high level of ion-acoustic turbulence observed experimentally. The role of conversion (quasiresonant coupling of Langmuir and ion-acoustic waves) in the energy transport in SLT is examined. In magnetoactive plasma, which is the case here, there is additional mechanism of slowing down of Langmuir waves -- resonant scattering of Langmuir waves on ion-sound waves. This mechanism leads to anisotropic heating of the plasma electrons. Nearly isotropic distribution function of superthermal electron found in the experiments argues against the leading role of this process in the energy transport.

*) L.N. Vyacheslavov V.S.Burmasov I.V. Kandaurov, E.P. Kruglyakov, O.I. Meshkov, A.L. Sanin, Proc. of Int. Conf. on Plasma Phys., Nagoya, Japan, v.1, p. 30-33, (1996).

P1 . 101

Electron Heating in Mirror by End Potential Plates

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Hot target plasma was obtained without additional heating in an open trap AMBAL-M from arc source located behind the mirror [1]. Previously longitudinal electron current in the plasma was found and investigated. In this paper the model of longitudinal electron current generation and the model of effective electron heating are presented and discussed. Radial and longitudinal profiles of plasma density, potential and electron temperature have been measured. Vlasov's equation and simplified Fokker-Planck equation in nonuniform fields have been solved. Development of instability, particle and energy balances in the mirror, transversal ion current in the plasma periphery have been considered in detail.

The arc source electrode potentials form a positive radial electric field on periphery, which together with the diffusion from ion-ion collisions leads to the significant transversal ion current in the transport region. The longitudinal electron current flows out into the mirror to provide quasineutrality. As the plasma density in the throat is low, the current needs the electric field accelerating the electrons to be formed in front of the throat. The found longitudinal electric field forms the population of fast electrons which transports the current. The electron flow heats the trapped electrons effectively (due to an ambipolar potential and the high velocity of the flow electrons) as a result of the Coulomb collisions. This «non-joule» non-turbulent effective heating of electrons by the current in an open trap has been first identified and investigated.

The model described shows the possibility of obtaining of hot plasma in a mirror by control of the radial profile of the potential. The plasma state obtained is close to the one which can be described basing on the classical (collisional) phenomena. This control of the radial profile of the potential and the «classical» character of the plasma obtained are pointed out as characteristic favourable features of open traps.

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P2 .043

Energy Confinement of the Finite β Plasmas in the Gas Dynamic Trap.

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The Gas Dynamic Trap (GDT) is an axisymmetric mirror device with the high mirror ratio for confinement of collisional plasma with hot ion minority. Hot ions are produced in the trap by oblique injection of high-power NBs into the collisional target plasma. Significant progress in plasma parameters was achieved with higher neutral beam power. Total power of six neutral beams with energies up to 17 keV and pulse duration of 1.2ms was increased from 2.5 to 4.5 MW. With these improvements, in the experiments with neutral beam injection the following parameters of the two-component plasma were achieved:

- target plasma temperature > 100 eV;
- target plasma density $1\text{-}10\times10^{13}\,cm^{-3}$
- mean energy of fast ions 3-10 keV
- fast ion density up to $1\times10^{13}\,cm^{-3}$
- plasma β $> 20\%$

The results of the following experiments will be reported: study of high beta plasma transport in the GDT; detailed study of fast ions energy balance and stability in high plasma performance shots. The consideration of energy confinement of the two-component plasma enables one to make the following conclusions:

- fast ions energy balance is determined by electron drag and charge-exchange losses;
- the energy distribution function of sloshing ions is quite close to that determined by Coulomb interaction with the bulk plasma particles;
- the longitudinal losses from the bulk plasma are dominated by collisional outflux through the mirrors.

The results of the cross-field energy transport measurements in the two-component plasma will be also given.

P1 . 134

Energy transfer from electron beam to dense plasma cloud at the GOL-3-II facility

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Recent results on beam-plasma interaction experiments and dense plasma heating at GOL-3-II facility are presented. GOL-3-II facility [1] is a open trap with 12m-long plasma column in the magnetic field of up to 5 T and up to 10 T in end mirrors. Section with magnetic pit was mounted near the entrance of solenoid. 0.2 MJ beam of 1 MeV electrons is injected into plasma through the input mirror.

Initial density in these experiments is nonuniform along the system. A cloud of 10^{16}-$10^{17}cm^{-3}$ plasma with 1-5m length near the entrance is created, the remaining part of plasma column has uniform density of 10^{15} cm^{-3}.

Primarily electron beam heats directly this uniform plasma due to two-stream instability. The measurements of the distribution function of plasma electrons by Thomson scattering show that characteristic mean energy of electrons ("temperature") is ~2 keV at a density of ~ 10^{15} cm^{-3}. The anisotropy of the distribution function of hot plasma electrons is observed. The electron distribution function during heating is formed due to turbulent fields excited in a plasma by the beam. Abnormally high (compared to the classical) electron collision frequency caused by the same fields leads to decrease in the plasma thermal conductivity, and hence increases the temperature and lifetime of electrons.

Further, these hot plasma electrons transfer their energy to electrons and ions of the dense cloud by binary collisions. In case of cloud density ~ 10^{16} cm^{-3} the electron temperature of the cloud is 0.3-0.5 keV, and the ion temperature increases up to 0.1-0.2 keV. Existing gradients of the temperature and density result in a set of pressure waves which are observed in the experiments.

1. M.A. Agafonov, A.V. Arzhannikov, V.T. Astrelin et al. Plasma Physics and Contr. Fusion (Proc. 23rd Europ. Conf., Kiev, 1996), vol. 38, No. 12A, p. A93, 1996.

P1 . 234

FEASIBILITY OF COHERENT VUV SOURCE BASED ON BEAM-PLASMA SYSTEM

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Plasma-based systems are often used as sources of short-wavelength emission, including the coherent ones (see, e.g., [1]). In this paper a new approach to VUV generation is discussed. A high-power stream of keV-range electrons from 10^{15} cm^{-3} plasma, heated by a relativistic electron beam, serves as a source for excitation of laser media. A plasma bunch with ~10^{17} cm^{-3} density and ~50 eV temperature is used as an active medium. Prospects of achievement of inverse population in the experiments at the GOL-3-II facility [2] are considered.

Feature of our approach is that the column of low density plasma is *de-facto* transformer of flux of 1 MeV electrons of the initial electron beam to flux of hot plasma electrons with essentially higher current density. In this case specific energy deposition per atom of laser medium is much higher than in schemes with direct pumping by an electron beam. This enables to reach higher temperature and ionization degree of an active medium, and gives prospects for achievement of generation in shorter wavelengths at comparable parameters of the electron beam.

Several *Ne*-like and *Li*-like ions with population high enough in a relatively wide interval of plasma temperature are chosen as primary candidates for VUV generation (*Mg* III, *Al* IV, *Si* V, *C* IV, *N* V). Calculated gain for 10^{17} cm^{-3} density estimated to be $6\cdot10^{-4}$-$5\cdot10^{-1}$ cm^{-1} [3].

Preliminary experiments were carried out using uniform magnetic field on the GOL-3-I facility. Dense cloud of 5% N_2 + 95% H_2 mixture was injected into the device at 5 m distance from the beam input with density up to $8\cdot10^{15}$ cm^{-3}. Power of flash of VUV emission with $\lambda <$ 100 nm exceeds 10 kW/cm^3, that gives total power, radiated by the cloud, $P > 10$ MW and total energy of $Q \sim 100$ J (initial energy content of the beam was ~ 40 kJ in this case).

Experiments on VUV generation on the GOL-3-II facility are supposed to be done in special short trap with mirror ratio ~5 for further increase in specific parameters of the dense cloud and in its lifetime. Upgraded experimental facility is under tests now. This work is partially supported by the Russian Foundation of Basic Research, project 96-02-19436.

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P2 . 233

Space Charge Compensation in Ion Beams for Isotope Separation

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A deep space charge compensation of high intense ion beams is necessary for efficient isotopes separations as for other applications of intense ion beams. A big attention for space charge neutralization was attracted from the first time of electromagnetic isotope separation development in the 30's up to lest development of low energy ion implantation [1]. Many results of space charge compensation for electromagnetic isotope separation summarized in the book [2]. In all previous investigations of the space charge compensation of positive ion beams it has been assumed that the compensating particles are electrons. However, in the environment of an isotope separation where the complex halide and hydride molecules with high electron affinity are often used as working gases, there is a very high probability of negative ion formation. In this situation, the presence of the negative ion can introduce a very important feature for space and surface charge neutralization [3]. Indeed, it may be the space charge compensation by negative ions is the determining factor for productive operation of the large scale ion beam industry but so far this circumstance has not been investigated. Some observations of improving of the space charge compensation and beam stability by an electronegative gases introducing in the experimental isotopes separation at the VEZUVII 8M device with optimized extraction system will be discussed. Very strong difference in space charge compensation with electronegative and noble gases cold be evidence of importance of the negative ion formation for stable space charge compensation. A possibility of positive ion beam overcompensation by heavy negative ions will be discussed.

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P4 . 138

Violation of Parity in Nonlinear Saturated State of Drift Vortices

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The nonlinear saturated state of the Kelvin-Helmholtz (K-H) instability have been investigated experimentally in detail. The adjustable radial electric field profile responsible for the inhomogeneous $E \times B$ flow profile was controlled by electrodes at the plasma-column ends [1]. In the experiments, stationary turbulence was generated in a rotating system with nonlinear energy transfer over scales from the pumping region (azimuthal wave number $m \sim 10$) to the dissipative region ($m \sim 1$), so that the regions of energy source and sink were very well separated.

In our experiments it was found that the observed amplitudes were strongly different for odd and even azimuthal modes in the nonlinear saturated state. It was shown that this violation of parity was determined by the sign of the dominant mode. When the dominant mode $m = 1$ was present, all the observed odd modes ($m = 1,3,5,7,...$) had amplitudes order of magnitude higher than their the even neighboring mates. Similar effects were observed when $m = 2$ mode was dominant, then the prevalence of even modes was clearly present. Thus, the nonlinear interaction of modes with each other are determined by the parity of the predominant mode and vortices of like polarity have the largest amplitudes.

Explanation of the observed phenomenon can be found in terms of interacting helicity modes. The lack of mirror symmetry (the non-zero mean helicity) is generally present in turbulent flow generated in rotating systems. The study of interacting helicity modes [2] indicates that non-linear interactions are weaker when the interacting vortices have like polarity and that vortices of opposite polarity have a tendency to interact more strongly. Thus, the presence of helicity exerts a constraint on the energy cascading process and all the vortices, that coexist in saturated state, have the same polarity (corresponding to a state of maximal helicity at each wave-number magnitude).

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