23rd European Physical Society Conference on

Controlled Fusion and Plasma Physics

23RD
FUSION
KIEV
1996

Abstracts of Invited and Contributed Papers

Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine

24-28 June 1996

Editors: I.F. Goutych, D. Gresillon, A.G. Sitenko

PLASMA HEATING BY HIGH-ENERGY CONTENT MICROSECOND ELECTRON BEAM AT GOL-3-II FACILITY

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GOL-3 facility is aimed for study the interaction of microsecond electron beam with a plasma and its fast heating. First stage of this facility, described in [1], was operated for more than six years (see, e.g., [2,3]). Recently the second stage named GOL-3-II was assembled and put into operation.

In the GOL-3-II facility the plasma column has 12 m length compared with 7 m for the first stage. Energy content of the capacitive storage for magnetic field supply has been increased from 10 MJ to 15 MJ. It allows to have the magnetic field of up to 5 T in the homogeneous part of the solenoid and up to 10 T in its end mirrors. Key feature of the upgrading is expected essential increase in the energy content of injected into plasma electron beam. The high power electron beam generator U-2 is used now for new beam-plasma interaction experiments. This generator was shown to produce the beam with energy content of up to 0.3 MJ.

Results on transport of the high-power microsecond electron beam through the 12 m plasma column, beam relaxation in the plasma, plasma heating and mirror confinement are presented. At plasma density of $\sim 10^{15}$ cm^{-3} the reached electron temperature is higher than 1 keV.

1. *A.V.Arzhannikov, A.V.Burdakov, V.A.Kapitonov et al.*, Plasma Physics and Contr. Fusion (Proc. 15-th Europ. Conf., Dubrovnik, 1988), vol 30, No.11, 1571.

2. *A.V.Arzhannikov, A.V.Burdakov, V.V.Chikunov et al.*, Proc. 9-th Int. Conf. on High Power Particle Beams (Washington, 1992), vol.1, 127.

3. *V.T.Astrelin, A.V.Burdakov, V.S.Koidan et al.*, Proc. 21-st Europ. Conf. on Contr. Fusion and Plasma Physics (Montpellier, 1994), vol.1, 498.

Characteristics and Mechanisms of Hot Initial Plasma Creation in the End System of AMBAL-M

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Characteristics and mechanisms of hot initial plasma creation in the end system of a completely axisymmetric ambipolar trap were experimentally studied in detail. The plasma created in the end mirror has the electron temperature ~50 eV, the ion energy 200 eV and an average density $\sim 6\cdot 10^{12}$ cm^{-3}.

For creation of hot initial plasma in the end system, a plasma stream with the developed low-frequency turbulence is used. The plasma stream is generated by an annular gas-discharge source of cold plasma, placed in the region before the entrance throat. Electrostatic oscillations with a broadband frequency spectrum developing in the plasma, lead to stochastic anisotropic ion heating and subsequent electron heating.

The most crucial factor providing hot initial plasma production, is the existence of longitudinal thermal insulation of the heated electrons in the end system from the cold electrons in the plasma source. Measurements of plasma potential indicate that the minimum of the potential constituting a thermal barrier is produced in the plasma.

Longitudinal electron current of 1 2 kA flowing in the plasma along the magnetic field was detected and studied. This current originally has an annular structure, subsequently compressing to the axis. The anomalously fast compression of the current is accompanied by the rise of transverse magnetic field fluctuations, which, possibly, also reduce longitudinal electron thermal conductivity.

The plasma is macroscopically stable at the filling stage as well as during decaying. The measured longitudinal energy losses from the plasma are close to classical, and the transverse losses are smaller than the longitudinal by a factor of several tens. The obtained initial plasma has appropriate target properties both for neutral beam injection and for ECR and ICR heating.

The Plasma Neutron Source Simulations in the GDT Experiment. (Kiev, Ukraine, 24-28 June 1996)

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Abstract

The paper reports on the results of recent experiments of the GDT facility which were aimed on the simulation of the physical processes in a Gas-Dynamic-Trap-Based Neutron Source. The GDT experiment is an axially symmetric magnetic mirror with a high mirror ratio and mirror-to-mirror distance exceeding the ion mean free path of scattering into loss cone. It consists of a 7m central cell bounded from each ends by axially symmetrical min-B anchor cells of an expander or/and cusp configuration. Initial plasma has been produced by plasma guns. Central cell losses sustain the anchor cell plasma density which is high enough for stability of the entire system. Magnetic field at the midplane was 0.22T, mirror ratio was varied in the range 12.5 - 75. We heated central cell plasma and provided energetic ions build-up by injection of six neutral beams at 45^{o} to the trap axis. Total injected power of 13.5-15 keV neutral beams was up to 3.5MW in 1.2ms pulses.

The end cell of an expander type [1-3] and cusp [4,5] have been proposed and tested experimentally. In the both cases, the end cell plasma is fed by collisional losses from the central cell through the linking mirror. Having a number of attractive features (compactness, high neutron flux, etc.) stemming primarily from its axial symmetry, gas-dynamic trap can be used as a 14MeV neutron source for fusion materials and components test [5]. To test basic physical principles of the source operation a program of work to study plasma stability and confinement is being undertaken. The issues related to the simulation of the main operational regimes of the source were also addressed. In this paper we present the results of development of plasma start-up scenarios applicable to the neutron source conditions, measurements of the energetic ion parameters including local measurements of the angular spread and energy distribution function. The paper also contains an analysis and interpretation of the recent experimental results on the stabilization of the MHD modes in GDT by the remote anchor cells and projection of the results to the neutron source conditions.

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Studies of plasma axial confinement and transverse transport in the GDT experiment.

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The GDT (Gas -Dynamic Trap) is an axisymmetric high mirror ratio open trap for the confinement of the collisional plasma. The most important practical application of the Gas-Dynamic trap could be the development the GDT-based intensive source of thermonuclear neutrons (~14 Mev) for material testing and other applications. The experimental program on the GDT-device is basically oriented to creating of the plasma physical database which can be used in the development of the neutron source.

During two last years the GDT facility was upgraded to obtain enhanced capabilities of the main subsystems, thus providing the substantial increase in plasma parameters.

Axial energy and particle losses in the GDT have been studied experimentally. The data were obtained with a movable bolometer in the region behind the mirror and a gridded retarding potential endloss analyzer located at the end wall. The amount of energy carried out from the trap by an electron-ion pair was measured to be (8.7±1.8) Te, mean energy of the ions striking the end wall was 65±0.2 Te, electrostatic potential drop between the end wall and the central cell was 4.8±0.2 Te. These values are in a reasonable agreement with the theoretical estimates.

The influence of the end-wall electron emission on the axial energy confinement has been investigated. It was shown that 40-60 times decreasing of the magnetic field between mirror and the end-wall results in strong reduction of electron heat flux independently on the the electron emission properties of the end wall.The mechanisms undelying the above mentioned phenomenon is discussed.

Transverse plasma transport was investigated in the GDT using the detail measurements of the energy global as well as local energy balance. The global power balance data indicate that in the stable regimes of operation transverse energy losses amount of 20-50% of the axial power losses.

Effect of a Nonuniform Radial Electric Field on Sheared Toroidal Rotation and Bootstrap Current

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Noninductive current generation has important applications to future tokamak reactors like steady state operation and current density profile control. This paper presents a new current drive mechanism generated by a sufficient shear of the radial electric field. The physical origin of the mechanism lies in the difference of the mean toroidal drift velocities E_r/B_p between the trapped electrons and ions due to the effect of the ion finite banana width coupled to the plasma pressure gradient and electric field inhomogeneity. The published theories of this process neglect the radial electric field inhomogeneity encountered by the ion along its banana orbit. The neglect of the impact of this inhomogeneity on the ion toroidal drift velocity E_r/B_p is valid if the scale length $L_E \cong |\nabla \ln E_r|^{-1}$ over which the velocity shear occurs is large compared with the width of the ion banana orbit, $\Delta_b = q\rho_i\epsilon^{-1/2}$. Here q the safety factor, ρ_i the ion Larmor radius and $\epsilon = a/R$ the inverse aspect ratio. If L_E is comparable with ion banana width Δ_b, the shear will strongly modify the toroidal rotation velocity and cannot be neglected. Since the ion banana width greatly exceeds the electron banana width, the impact of the shear on the electron toroidal rotation velocity is therefore reduced. This change in relative velocity of electron and ions in their toroidal flow seems to be sufficient to produce a significant bootstrap current variation.

To evaluate the effect of the nonuniform profile $E_r(r)$ on bootstrap current distortion we apply a simple model integrating the radial electric field along the ion banana orbits. It was obtained that the additional current term δj_{bs}, correcting the neoclassical bootstrap current j_{bs}, is

$$\delta j_{bs} = -\alpha \cdot \Delta_b^2 \cdot \frac{e}{T} \cdot \frac{\partial E_r}{\partial r} \cdot j_{bs},$$

where α is constant on the order 1. For $(\partial E_r/\partial r) < 0$ the ions drift in the direction of the bootstrap current in the $E_r \times B_p$ drifting frame of the electrons. It can be seen that in the case of $eE_r\Delta_b \sim T$ the shear current term δj_{bs} can be comparable with j_{bs}. The expected value of this term for some present devices and its experimental evidences are considered.

An important component of the considered current drive mechanism is the source of a thin shear layer ($L_E \sim \Delta_b$) of a nonuniform radial electric field. There are presently two plausible mechanism which have the strong influence on the radial electric field distribution and so they have the potential to provide a spatially tunable current source. Some recent experiments, showing that both the neutral beam injection and the gyrotron pulse can to create a sufficient radial shear, are discussed. However, the detailed analysis of these processes, as well as the other processes determining toroidal rotation, is beyond the scope of the present report.

Manifestation of wave collapse in developed strong Langmuir turbulence in a magnetic field

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Experimental study of Langmuir turbulence that is well above the threshold of modulational instability is presented. Broad spectrum of Langmuir waves is driven by relativistic electron beam in a magnetized plasma where magnetic contribution to the dispersion relation of Langmuir waves exceeds the thermal contribution in the interval between pumping and damping regions in a momentum space. Dimensions of observed turbulent plasma volume and the time scale of the experiment are much greater than the size and the life-time of a single caviton, which allows the study of developed turbulence regime. Two effects of the collapse occurrence under the above stated conditions are observed for the first time: generation of tails of plasma electron distribution function and high level of short-wavelength low-frequency density perturbations. The later phenomenon is enhanced due to weak damping of ion-acoustic waves in nonisothermal (Te >>Ti) plasma used.

Plasma electron distribution function is resolved by noncollective scattering of Nd-glass laser light. Two simultaneously operated receiving systems are employed: 90°-scattering for measurements of the electron bulk and 8°-scattering for studying high energy tails. Observations detect electrons heated up to 150Te that store a substantial portion of the total plasma energy. In this paper the results of observation of the ion-acoustic turbulence are also shown. These low frequency fluctuations are studied by the method of collective scattering with a pulse CO_2 laser. An analysis of the ω- and k-spectra measurements shows that the spectral density of the low-frequency turbulence is by several orders of magnitude higher than the thermal one. The estimation of the minimal size of collapsing caviton based on the k-spectra analysis gives a value $l_{min}<30\ r_D$.