LONGITUDINAL CURRENT AND FLUCTUATIONS IN THE INITIAL PLASMA OF THE AMBAL-M DEVICE

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The problem of current and magnetic field generation by plasma has a long history. But despite of this fact there are very little direct experiments in this field. This article deals with phenomena of generation of longitudinal current in axisymmetric open trap AMBAL-M. The connection between magnitude of the current and level of turbulence fluctuation of the plasma has been revealed. The phenomenological self-consistently model of radial profile of current has been offered.

1. Arrangement of experiment

The experiment was carried out on the axial-symmetric open magnetic trap AMBAL-M [1]. The plasma was generated by arc plasma gun located in the magnetic field. The current of electrons frozen in the plasma jet creates the unhomogeneity radial electric field. It is produce the differential rotation of the plasma column in crossed $\vec{E} \times \vec{B}$ fields that lead to excitation of Kelvin-Helmholtz instability. Its instability caused an increase of the transverse plasma conductivity and thus tended to flatten the radial profile of the velocity of the rotating plasma column. In this case some part of the kinetic energy of the rotating plasma was converted into thermal energy of the plasma flows [2]. Moreover, there appears a longitudinal current along device. First it was explained by closing some current loop from source via vacuum chamber. But observation of the regime then its current larger total current in the source induced new idea explaining current generation.

The local measurements of current were made by pickup magnetic probe. Results of experiment for different location along axially direction is shown on Fig. 1. One can see that profile dynamics of current density along axial direction is characteristic for diffusion process. The radial profile of some plasma parameters for z = -116 cm are given in Figs. 2 – 3 (z = 0 cm - trap center, z = -345cm - output of plasma source, z = +280 cm - plasma receiver, z = -116 cm input plug, z = +116cm - output plug). There are similarity between pairs of radial profiles: density - current and fluctuation dispersion - electron temperature. Some Rogowski coil controlled total current in plasma column. It was 1.6 kA near output of plasma source and 1.0 kA near plasma receiver. The experiments displayed that value of total current is in direct proportion to magnitude of magnetic field (Fig. 4). Spectral analyze of signals from magnetic probe and Langmuir probe is shown on Fig. 5. The low-frequency peaks for both signals are similar and be caused by Kelvin-Helmholtz instability.

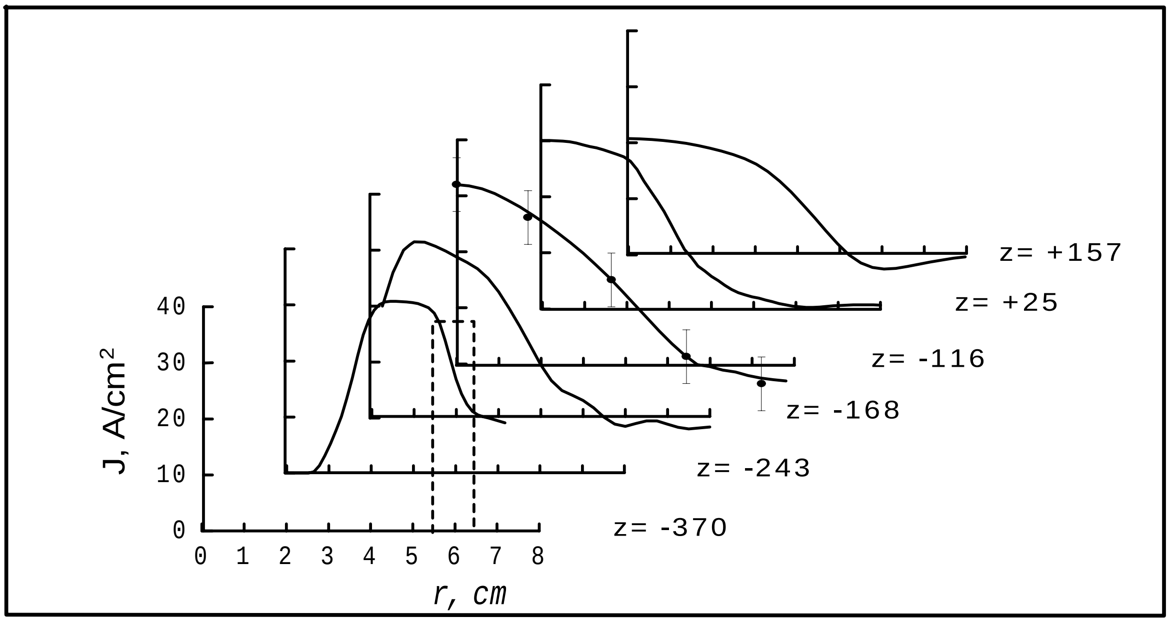

Fig. 1. The radial profile of current density for different longitudinal position.

Complicated character of turbulent processes in magnetized plasma forced us to consider a phenomenological model. Suppose that current induces by electromotive force ε_T connected with instability. Naturally and simply measurable parameter of turbulence level is dispersion of electrostatic fluctuation $G_T =< \varphi(t)^2 >$. Assuming that electromotive force ε_T and diffusion coefficient D_T is in direct proportion to G_T. Assuming also that coefficient conductivity is following function: $\sigma_T = \sigma_0 \cdot \sigma_T / (\sigma_0 + \sigma_T)$, where σ_0 is Spitzer coefficient of conductivity, σ_T - coefficient conductivity connected with turbulence. Latter can be estimate as $\sigma_T \approx c^2 / D_T$. Thus one obtains a simple phenomenological model for the radial dependence of current density with some parameter set. Constraining these parameters by experimental facts or plausible hypothesis one can give possibility to compare model with experiment. Result of this program for our case present in Fig. 6. From this figure we notice that enhancement electron temperature causes flatten radial profile of current density. In the case $\sigma \cdot D_T / c^2 >> 1$ (in our experiments $D_T^{\max} = 3 \cdot 10^5 cm^2 / \sec$ and this condition realizes at $T_e \geq 10eV$) the plasma conductivity is determined by only turbulence level and doesn't dependent from electron temperature. Then density of current generating by turbulence motion is constant and doesn't depend from r. In such a way the controlling factor for current density profile is thermal conductivity condition that determines T_e. This condition induces radial profile similarity of plasma density and current density. The similarity of radial profiles of electron temperature and fluctuation dispersion can be explained by heat increase in domain of high turbulence level at r = 5cm. It is induced by decreasing of plasma conductivity at constant value of current density.

2. Discussion

Let us discuss the physics mechanism providing ability to generate a current in plasma.

It is known [3] that the helix turbulence motion of conductivity medium can generate electrical field along magnetic field direction. The parameter characterizing this process is helicity - $< u \cdot rot\, u >$ and electrical field is defined by equation: $\varepsilon_T = \alpha \cdot B - \beta \cdot rot\, B$. Average rotation inherent to processes with non-zero helicity. The turbulence motion without initial helicity can acquire it if one takes part in rotation. Plasma source used in this experiment characterizes by high magnitude of radial electric field that together with perpendicular magnetic field provides average rotation and instability exciting simultaneously. The simple estimation shown:

$$\alpha = -\tfrac{1}{3} \cdot \int_0^\infty < \vec{u}(\vec{r}, t) \cdot rot\, \vec{u}(\vec{r}, t - \tau) > d\tau \approx \tau_{cor} \cdot u^2 / \lambda_B \approx D_T / \lambda_B \approx$$

$$\approx 60 m / \sec ; \quad E_T \approx \alpha \cdot B \approx 45 V / m; \quad J_{\max} \approx \sigma_T \cdot E_T \approx 120 A / cm^2 \qquad (1)$$

where D_T - plasma diffusion coefficient, λ_B - characteristic length of changing of magnetic field.

Second way for current generating or amplifying may be connected with ambipolar plasma diffusion in a transverse magnetic field (by an analogy with bootstrap-current in tokamak). Estimation of the order of magnitude gives

$$J \approx \sigma_0 \cdot E \approx \sigma_0 \cdot [\vec{u} \times \vec{H'}] / c \approx \frac{\sigma_0 \cdot D_T \cdot \nabla n}{e \cdot c \cdot n} H', \qquad (2)$$

where H' - initial azimuthal magnetic field. The numerical estimation of its value for our case is $J \approx 200 A$ that is insufficient for our case.

References

[1] T. Akhmetov, V. Belkin, E. Bender et. al.: Plasma Phys. Reports **23**, 919 (1997)
[2] A. Kabantsev and S. Taskaev: Sov. J. Plasma. Phys. **16**, 406 (1990)
[3] H.K. Moffat: Magnetic Generation in Electrically Conducting Fluids. Cambridge (1978)

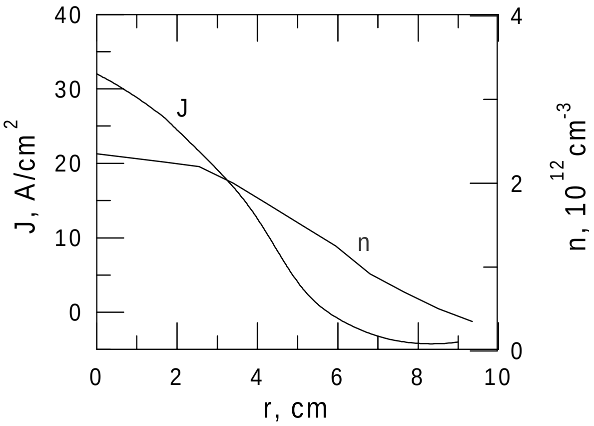

Fig. 2. Radial profile longitudinal current density and plasma density in input plug (z=-116cm)

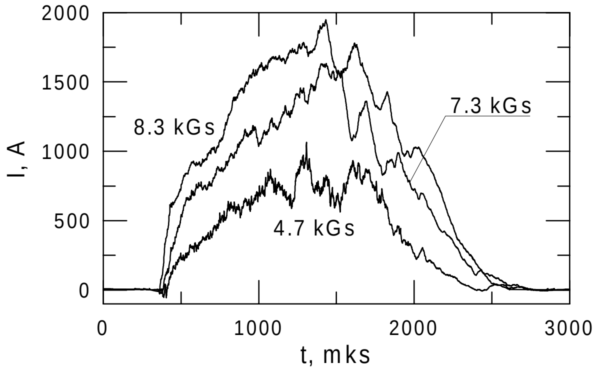

Fig. 4. Dependence of value of total longitudinal current from magnitude of magnetic field in AMBAL-M device.

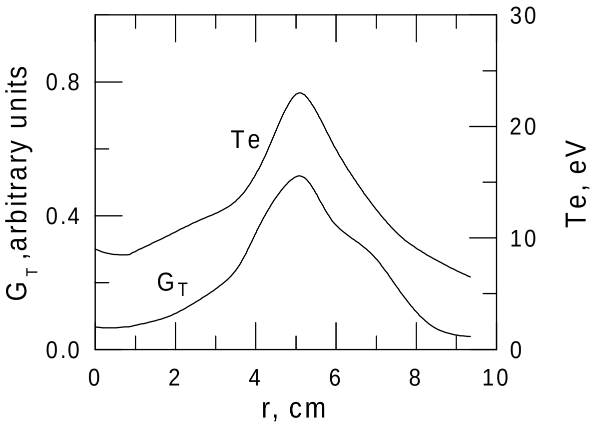

Fig. 3. Radial profile electron temperature and value of fluctuation dispersion of plasma potential in input plug (z=-116cm).

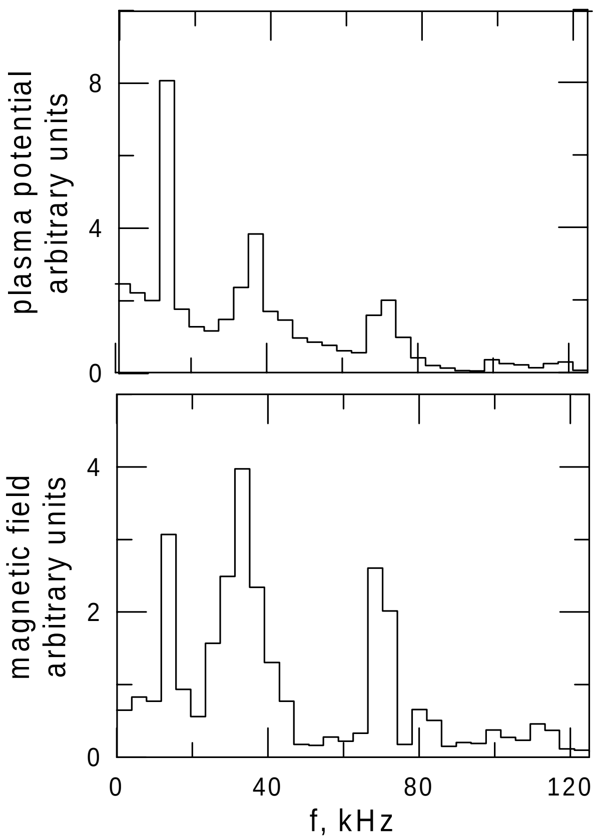

Fig. 5. Fluctuation spectrums of magnetic fields and plasma potential in input plug (z=-116cm).

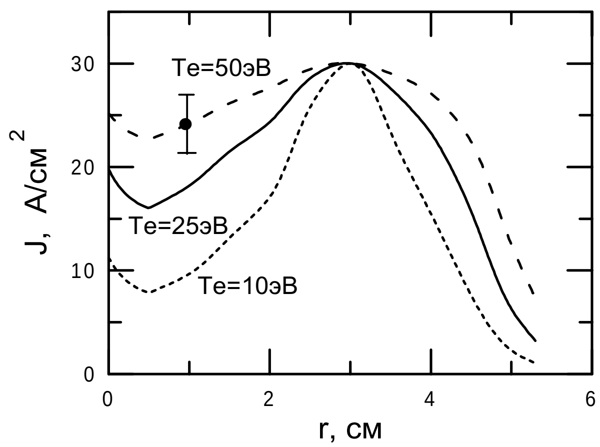

Fig. 6. Radial profiles of longitudinal current computing from phenomenological model.