OPTIMIZING OF THE BANANA-DRIFT CURRENT GENERATION IN THE TOKAMAK ITER.

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In Ref. [1], the results of simulation of different modes of ITER stationary operation are presented. In particular, it provides data for operation with a small negative shear (WNS). In this mode, the current in the plasma is created by driving with help of neutral atom injection and of the radiation on the ion, electron and lower hybrid frequencies. Full size of this noninductive current is 5.3 MA, which together with the bootstrap current (3.7 MA) provides a plasma current with magnitude of 9 MA.

In Ref. [2] it is described a method for additional self-induced longitudinal (banana-drift) current driving in ITER-like tokamak with help of ion cyclotron heating of minority ions in the perpendicular to the magnetic force lines direction which allows to replace the current generated in the tokamak by other methods. Under calculations the back current was taken into account [3].
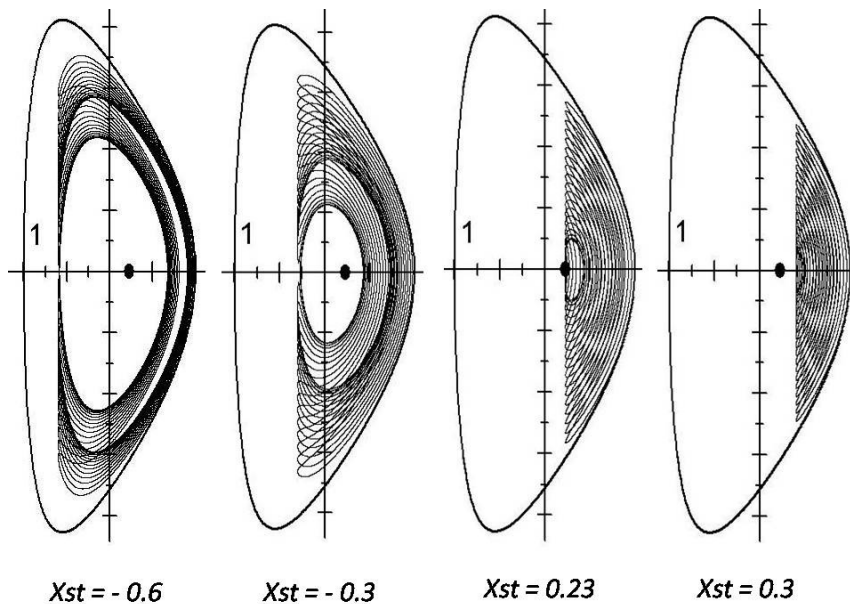
In this paper, the estimation of the banana-drift current maximum value which is driven during crossing of the resonant layer by minority ions is given.

Details of these calculations are described in [2]. Calculations were performed for the

Fig.1

various resonant layer positions, the energy of the accelerated ions and the bulk plasma temperature in the tokamak with non-circular magnetic surfaces.

In Fig.1 orbits of the particles heated to an energy of 1.25 MeV with help of radiation on ion cyclotron frequency for the case where the resonance layer is placed at different values of $x_{st} = r_{st} / a$, where a is the minor tokamak radius. Fat points in this figure mark the position of the magnetic axis. The figure shows that when the resonant layer is disposed in a strong, relative to the magnetic axis field ($x_{st} = -0.6$) near the center of the plasma column it is a region, in which the particle orbits are absent, and hence in this region the banana drift current is absent so. If the resonant layer passes through the magnetic axis ($x_{ax} = 0.23$) or through the point in a relatively weak field, the orbits are located at a weak magnetic field part.

Fig.2

In Fig.2 one can see the current density distribution when $x_{st} = -0.6$ (curve 1) and when $x_{st} = 0.8$ (curve 2). It is seen tha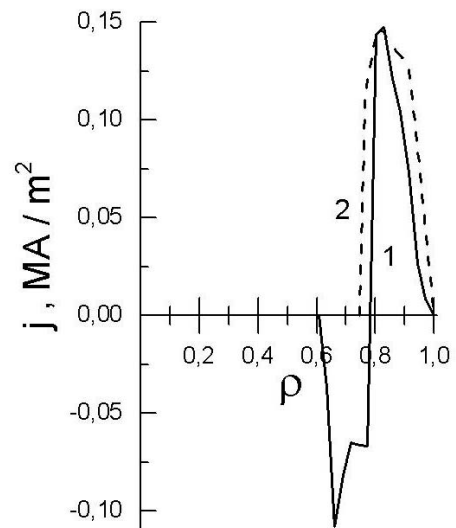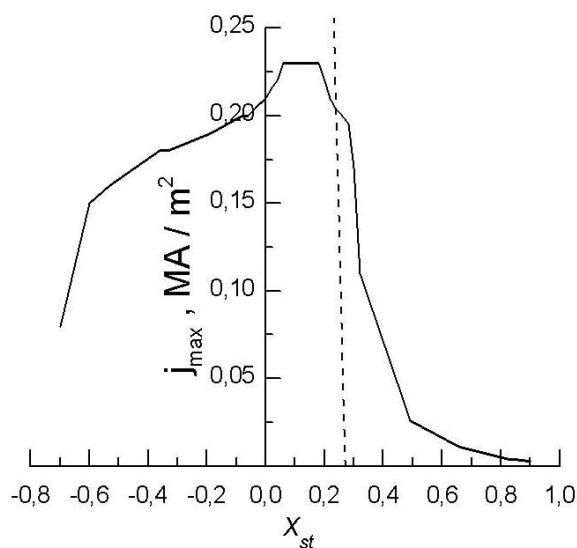t the current density maximum values are at the same value ρ, but the difference in the current densities is equal to 19. When the resonant layer is located in high field side it is an area with negative current. Here and later $\rho = \sqrt{1 - \psi / \psi_{ax}}$, where ψ_{ax} is the ψ value on the magnetic axis (at the plasma boundary $\psi = 0$).

Fig.3

In Fig. 3 it is shown the dependence of current density maximum on the resonance layer position. It is seen that when resonant layer is located on the high field side the current density maximum is almost unchanged when $-0.5 \le x_{st} \le 0.23$ and when $x_{st} > 0.23$ it rapidly decreases.

Fig. 4 shows the total current value dependence on the position of the resonant layer. The dotted line shows the position of the magnetic axis ($x_{ax} = 0.23$). It is seen that the maximal value of the total current is at the resonant layer position which is shifted relative to the magnetic axis in the high magnetic field side about $\Delta x \approx 0.1 / A$.

Fig.5 shows the results of self-induced current estimation during the simultaneous heating of the minority ions when resonant layers are located at different positions. Curve 1 – the total value of the banana-drift longitudinal current, curve 2 - $x_{st} = 0.06$, curve 3 - $x_{st} = 0.23$ (magnetic axis), curve 4 - $x_{st} = -0.33$. The minority density for currents, which are represented by curve 2 and 3 is $1 \cdot 10^{18} \, \text{m}^{-3}$ and by curve 3 is $2.5 \cdot 10^{18} \, \text{m}^{-3}$.

In Fig.6 one can see the radial dependence of all noninductive current values in ITER. The curve 1 – the total noninductive current in the ITER tokamak [1], curve 2 – total self-induced current which is sum of asymmetry current [4,5], bootstrap current and banana-drift current, curve 3 - the total banana-drift current (curve 1 in Fig.5), curve 4 - bulk plasma asymmetry current, curve 5 – the bootstrap current.

Fig.4

The total asymmetry current in this case is 0.84 MA, the current which is generated the case when the resonant layer passes through the magnetic axis is equal to 1.48 MA, when $x_{st} = 0.06$ one is equal 1.9 MA, and when $x_{st} = -0.33$ one is equal to 1.13 MA.
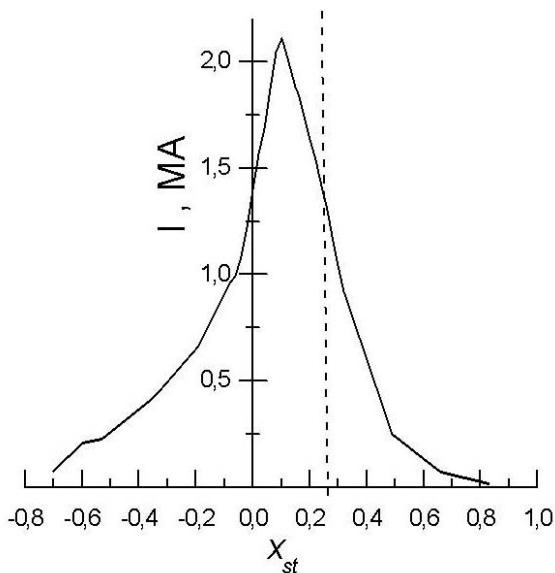
Thus, the total self-induced current is equal to 9 MA. This value is the same as one is indicated in Ref.[1] .

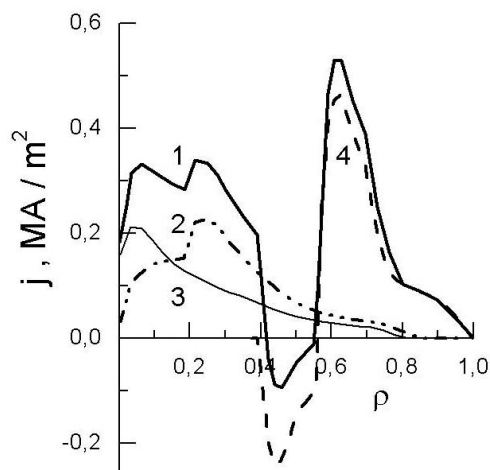The paper [6] describes the conditions for obtaining the so-called Super-H mode, in which a fusion energy output significantly increases in comparison with the conventional H mode one. One of the condition for this mode achievement is the presence in plasma of 1% of argon ions. Such amount of Ar ions increases an effective plasma charge.

Fig.5

In Fig.7 the dependence of the banana-drift current generated when $x_{st} = 0.1$ on plasma effective charge Z_{eff} is shown. From the figure it is seen that when Z_{eff} increases from 2 to 6, the value of the banana-drift current increases by about 40%. This is due to the fact that with increasing of Z_{eff} the back current value is reduced.

Calculations performed at other temperatures (pressures) of the bulk plasma have shown that the
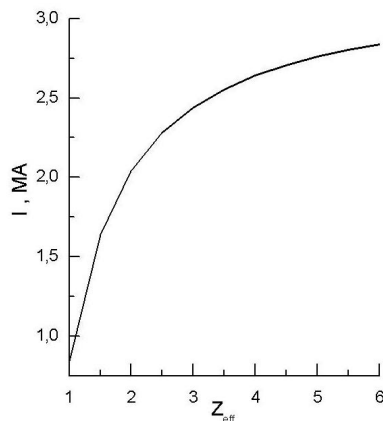

Fig.6

optimal value of the resonant layer position shifts with respect to the magnetic axis in the direction of a high field side of about $0.1 / A$.

Thus it is shown that by changing the number of accelerated minority ions, the energy to which they are accelerated and the position of the resonant layer it is possible completely replace a non-inductive current generated by other methods (radiation on electron-, ion- and lower hybrid frequencies and the injection of fast neutral atoms), and approximately simulate the radial distribution of non- inductive current.

Fig.7

So, we can conclude that the self-induced currents (bootstrap current, asymmetry current and banana-drift current) can provide steady-state fusion reactor operation.
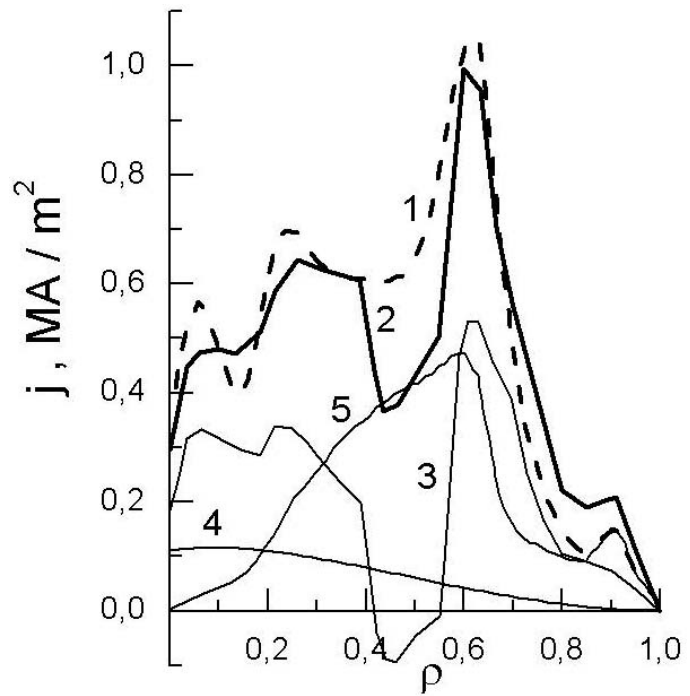
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