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Cross field Passing Electrons as an Initiator of Closed Flux Surface in Toroidal ECR Plasmas

磁場を横切る高速通過電子群による初期磁気面形成

MAEKAWA Takashi, TANAKA Hitoshi, UCHIDA Masaki, WATANABE Fumitake, YOSHINAGA Tomokazu*)

前川孝、田中仁、打田正樹、渡辺文武、吉永智一*)

Kyoto University, National Defense Academy of Japan*)

京都大学エネルギー科学研究科、防衛大学校応用科学群*)

A mode that describes non-inductive initiation of closed flux surface observed in EC-heated toroidal plasmas is presented. First an equilibrium toroidal current flows in open fields under a weak external vertical field. The fluid theory relates the pressure profile to the current profile. The current increases as the electron pressure increases. The current channel expands vertically along the ECR layer. When the vertical field inboard to the current channel is reduced significantly, cross field passing orbits of electrons appear. The CFP electrons carry an additional current that closes the filed lines. The current profile is calculated by using the velocity distribution of CFP electrons that is obtained by using the Fokker Planck theory.

An initial closed flux surface has been found to be produced by ECH under a weak external vertical field B_{VEXT} in a number of tokamaks, both in small and large devices, including CDX, LATE, DIIID, and JT60U [1-4] etc . If this non-inductive technique is also effective to initiate closed flux surface in fusion grade devices, it may relax the demand of large inductive voltage from central solenoid for discharge initiation. Present study attempts a modeling of this non-inductive process.

The model assumes that closed flux surface is generated via two steps. First, there appears a pressure-driven toroidal current as the plasma is EC heated so as to counter balance the pressure ballooning radial force of the plasma torus. This current is a kind of equilibrium current originated from the vertical charge separation drifts of electrons due to the curvature and gradient-B of the toroidal field B_T.

$$u_{VTF} = \frac{m\left(v_{//}^2 + v_{\perp}^2/2\right)}{qRB_{\phi}}$$

The vertical current density is proportional to the local electron pressure,

$$j_{VTF} = \frac{2P_e}{RB_{\phi}}$$

The ion contribution may be negligible in ECR plasmas. A return current that flows along the helical field lines to compensate charge separation make a toroidal current. While this current flows only in open fields, the vertical field inboard to this equilibrium current channel may be enormously reduced from the external vertical field B_{VEXT} when this current increases up to the limit of open to closed field. When this reduction attains to some level, which depends on the product of the major radius and the external vertical field, RB_{VEXT}, the second step sets in as follows.

Usually electrons are heated perpendicularly by ECH and the resulted energetic electrons are pitch angle scattered in both directions, forwardly and backwardly. In the external field of B_{VEXT} and B_T, however, they are immediately lost to the vacuum vessel before they are significantly pitch-angle scattered. The situation drastically changes when the equilibrium current and its field increases as mentioned above. In this stage some forward electrons referred to as cross field passing electrons are confined in open fields. They carry additional toroidal current that closes the field lines. The distribution on the confined area in the velocity space is numerically estimated by a simplified Fokker Planck model including EC-diffusion, pitch angle scattering and slowing down of energetic electrons due to collision with bulk particles. Various associated quantities including toroidal current and EC-power to maintain the distribution are also estimated.

Numerical results for two cases, one for a small low aspect ratio torus (Fig.1) and one for a conventional large torus, will be presented.

References

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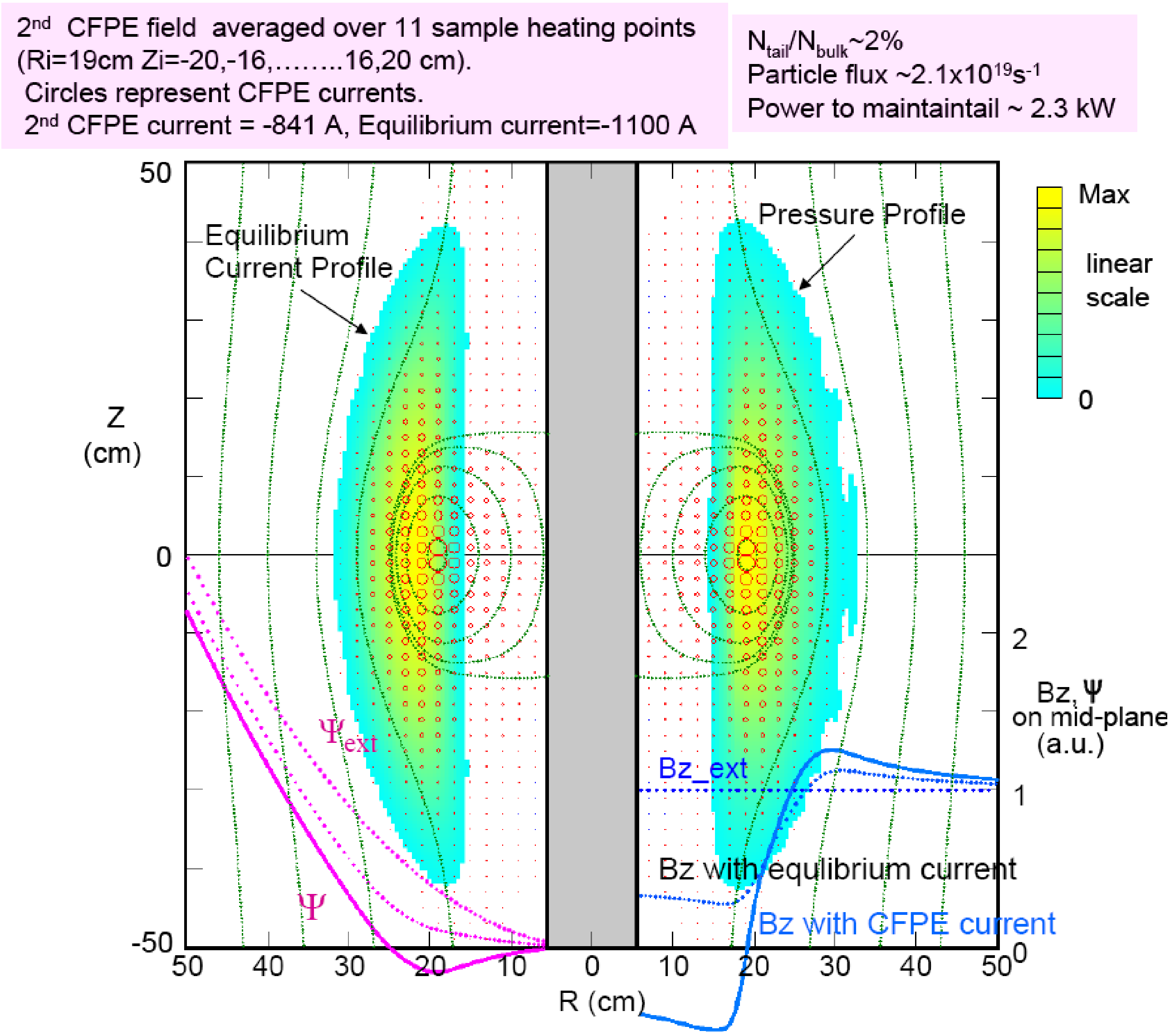

Fig.1. A case in small low aspect ratio torus