32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-1.028 (2005)

The Influence of Resonance Helical field on the Z_{eff} in IR-T1 Tokamak

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Abstract

The effect of resonance helical field (RHF) on effective ion charge, Z_{eff}, in IR-T1 tokamak is studied. The RHF in tokamak is an external magnetic field which can improve the plasma confinement. This field is produced by conductors wound externally around the tokamak torus with a given helicity.

The IR-T1 tokamak is a small air-core transformer tokamak with circular cross section and without conducting shell and divertor. It's aspect ratio is $\frac{R}{r} = \frac{45cm}{12.5cm}$. In IR-T1, RHF is generated by two of helical coils installed outside the vacuum vessel. The pulsed dc RHF configuration $(\ell = 2,3)$ has the optimal current and variable time. To understand how RHF affects the IR-T1 plasma, the theoretical calculation for magnetic field components on the main external field, toroidal, is discussed. Then the results are applied to calculation of Z_{eff} value through anomaly factor. Finally the theoretical results arise from RHF are compared with our previous results, obtained without RHF.

Introduction

The behavior of impurities in tokamak plasma is of primary importance in fusion [1]. Information on the behavior of impurities in tokamaks is important for several reasons. One is the impurity radiation. Impurity radiation can be a major source of power loss in tokamak and can induce or exacerbate instabilities or other wise detract from achieving favourable fusion plasma parameters. At high concentration, impurities prevent the plasma being heated. This is particularly a problem during the plasma start up phase since impurities radiate strongly at low temperature before they become ionized. So if we want to discharge repeatedly, we must control impurities in tokamak.

One of the best ways to control tokamak plasma is the use of external fields. One kind of these fields is resonance helical field (RHF). The RHF in tokamak is an external magnetic field which can improve the plasma confinement. This field is produced by conductors wound externally around the tokamak torus with a given helicity.

The aim that is followed in this article is to understand the effect of RHF on the Z_{eff} in addition to influence on the control of plasma. The previous work done on tokamaks based on Resonance helical field shows that the exact nature of the stabilizing mechanism arise from RHF is not yet clear. Probably the RHF produces a fixed helical structure in the plasma which hinders a rotation of the MHD modes and also there is a convective growth of the perturbation [2].

Since the facts of how RHF can affect on plasma control, is not clear, so it seems to be difficult to understand how RHF can impress Z_{eff} . To investigate this effect, this paper is organized as follows:

the second section is devoted to calculate the Z_{eff} value through anomaly factor (without RHF and with RHF). Our conclusions are left to the final section. we outline the effect of external resonance helical field components on the main field components, toroidal and poloidal fields in appendix.

Calculation of Z_{eff} through anomaly factor (α)

The anomaly factor α is defined as the ratio of the measured plasma resistivity η_p to the theoretical resistivity η_{11} predicted by spitzer, for pure hydrogen plasma [3]. The spitzer resistivity is:

$$\eta_{11} = 5.24 \times 10^{-5} \frac{Z \ln \Lambda}{T_e^{\frac{3}{2}}} \qquad (\Omega \cdot m) \tag{1}$$

Where Z is the ion atomic mass, $\ln\Lambda$ is the coulomb logarithm and T_e is the electron temperature in eV. For the estimation of the electron temperature it was necessary to perform experimental measurements of plasma current, loop voltage and electron density and to take into account the geometrical parameters of IR-T1 tokamak. The coulomb logarithm is

$$\Lambda = 1.5492 \times 10^{13} \frac{T_e^{\frac{3}{2}}}{Z^2 \sqrt{\bar{n}_e}} \qquad 2)$$

Where $\bar{n}_e$ is the average plasma density in m^{-3}. The electron temperature is calculated according to the energy balance equation for a tokamak discharge.

$$T_e = \frac{I_p V_\ell \tau_E}{2k\pi^2 R r^2 n_e} \tag{3}$$

Where I_p is the plasma current in A, V_ℓ is the loop voltage in V, τ_E is the energy confinement time in s, k is the Boltzman constant, R and r are the IR-T1 major and minor radii in m. for ohmic heating, plasma which is not too dense, the energy confinement time and safety factor q are given as

$$\tau_E = 7\times10^{-22}\,\overline{n}_e\, rR^2 q \quad , \quad q = 5\times10^{6}\,\frac{B_T r^2}{I_p R} \; , \tag{4}$$

Where B_T is the toroidal magnetic field in tokamak. The values of q, τ_E ,Λ, T$_e$, η_{11} and η_p , for the IR-T1 tokamak were calculated from experimental data as bellow:

$$I_p = 30kA,\; V_\ell = 1.5V,\, n_e = 1.1\times10^{13}\; cm^{-3}, B_T = 0.6\,T$$

Thus, the resulting values are:

$$q = 3.47\;,\; \tau_E = 0.7\,ms\;,\; T_e = 129\;eV\;,\; \Lambda = 6.9\times10^{6}$$

For hydrogen plasma in the IR-T1 the spitzer resistivity is $\eta_{11} = 0.56\times10^{-6}\Omega m$.

For Ohmic input power, the plasma resistivity is given by

$$\eta_p = \frac{r^2 V_\ell}{2RI_p} \tag{5}$$

Replace V_ℓ in Eq. (5), value of η_p for IR-T1 tokamak is equal with 0.86×10^{-6} and because we have defined Z$_{\text{eff}}$ as the ratio of the measured plasma resistivity η_p to the theoretical resistivity η_{11}, the value of 1.5 is obtained for Z $_{\text{eff}}$ in the IR-T1 tokamak [4].

When RHF is turned on, no Change in the main field components, toroidal, can be seen (refer to appendix). Since the toroidal component mains constant, we expect that the Z$_{\text{eff}}$ value will be unchanged through anomaly factor but experimental results show, although I_p and B_T value is unchanged but remarkable change is seen on the value of n_e and τ_E to provide these changes in anomaly factor, there is noticeable decrease at Z$_{\text{eff}}$.

keeping previous experimental conditions, following results are given:

$$n_e = 1.6\times10^{13} cm^{-3}\;,\; \tau_E = 0.98\;ms\;,\; T_e = 99.5\;eV\;,\; \Lambda = 3.8\times10^{6}\;,\; \eta_{11} = 0.86\times10^{-6}$$

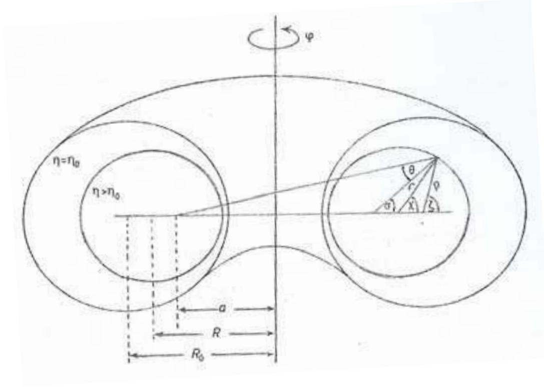
Then $Z_{eff} = \dfrac{\eta_p}{\eta_{11}} = 1.075$.

Conclusion

As the results arised from calculation of the effect of RHF on toroidal component show, there is no any change on it. So we expect that there will be another mechanism that controls the impurities level. We saw that by using RHF, Z$_{\text{eff}}$ decreased. Decrease of Z$_{\text{eff}}$ shows that the interaction of plasma-wall diminishes. The impurity movement circulation is cut due to unknown phenomena.

Appendix: helical magnetic field components

To calculate magnetic fields due to helical current filaments on the surface of a torus, two systems of orthogonal coordinates have been used to describe toroidal geometry :
a) quasi-toroidal, b) toroidal coordinates. A system of quasi-toroidal coordinates (ρ, ϕ, ξ) can be defined where the ρ =const surfaces



form a set of nested concentric toroidal surfaces with respect to the circular axis $R = R_\circ$ another system of torioidal coordinates (η, θ, ϕ) can be toroidal surfaces around the limit circle defined by R=a. the relation ship between these coordinates and Cartesian coordinates can be written as follows [5]:

$$x = (R_\circ + \rho\cos\xi)\cos\phi, \quad y = (R_\circ + \rho\cos\xi)\sin\phi, \quad z = \rho\sin\xi$$

By the use of Biot-Savart law, it can be shown that:

$$B_\eta = -bv\left(\frac{v'}{v}\right)^\ell \sin\phi, \quad B_\theta = bv\left(\frac{v'}{v}\right)^\ell \cos\phi, \quad B_\phi \simeq 0$$

Where
$$b = \frac{\mu_\circ I_\circ}{4a}\cosh p\beta\,\frac{2\ell-1}{2(\ell-1)} \quad , \quad v = \cosh\eta \quad , \quad v' = \cosh\eta'$$

$$\beta = -\ln\left(\lambda - (\lambda^2-1)^{1/2}\right) \quad , \quad \lambda = \frac{v'u}{vu'} \quad , \quad u = \sinh\eta \quad , \quad u' = \sinh\eta'$$

P: turns the short way

ℓ : turns the longway around the torus

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