EFFECT OF PLASMA ROTATION ON THE RESONANCE MAGNETIC PERTURBATIONS AT THE EDGE OF TOKAMAK PLASMAS

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In the frame of one-fluid MHD the pressure perturbation resonant excitation by external low frequency helical magnetic perturbations near the plasma edge is investigated. The plasma rotation plays a key role in this phenomenon. The plasma response has been taken into account. These pressure perturbations may affect stability of the ballooning and peeling modes.

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INTRODUCTION

Control of Edge Localized Modes (ELMs) is a critical issue of the present day large tokamaks and future ITER operation [1, 2].

Experiments at DIII-D have shown that ELMs can be suppressed by small external low frequency helical magnetic perturbations [3, 4].

In Ref. [5] the influence of an external helical field on the equilibrium of ideal plasma was investigated in the frame of MHD theory. A perfect shielding of the external resonant field was assumed.

Early in the frame of one-fluid MHD a possibility of the pressure perturbation resonant excitation (due to the plasma rotation) by external helical magnetic perturbations near the plasma edge has been shown [6], when the plasma response has being taken into account (a perfect shielding is not assumed).

In the present paper, the influence of these pressure perturbations on external helical magnetic field near the plasma edge is investigated. Considered plasma parameters are close to DIII-D experiments [3, 4].

Poloidal and toroidal plasma rotations are taken into account. The plasma rotation plays a key role in this phenomenon. The plasma response takes into account.

Note, that the toroidal rotation effects on ELM behavior were observed in experiments [4, 7].

1. BASIC EQUATIONS

We start from the one-fluid MHD equations

\[\rho \frac{dV}{dt} = -\nabla p - \nabla \cdot \pi + \frac{1}{c} [J \times B] \cdot \frac{dp}{dt} + \gamma_a \rho \nabla \cdot V = 0,\]

\[\text{rot } E = -\frac{1}{c} \frac{d}{dt} B, \quad \text{rot } B = \frac{4\pi}{c} J, \quad \text{div } B = 0,\]

\[\text{div } J = 0,\]

\[J = \sigma \left( E + \frac{1}{c} [V \times B] \right),\]

where \(\rho\) is the plasma mass density, \(p\) is the plasma pressure, \(J\) is the current density, \(\sigma\) is the conductivity and \(\pi\) is the ion gyroviscosity tensor, respectively.

In Ref. [5] the influence of an external helical field on the equilibrium of ideal plasma was investigated in the frame of MHD theory. A perfect shielding of the external resonant field was assumed.

In Ref. [6] the influence of an external toroidal field on the plasma equilibrium was shown [6], when the plasma response has been taken into account (a perfect shielding is not assumed).

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Note, that the toroidal rotation effects on ELM behavior were observed in experiments [4, 7].
\[ p_n = -\frac{i}{\Omega_n} \left\{ \frac{c^2}{R} B_{n0} F_n(a) \left( \rho_0 V_{m0} V_{a0} + \rho_0^2 B_{n0}^2 \right) + \omega_n p_0 V_{a0} + \frac{\omega_n B_{n0} c^2}{R} \left[ \frac{(aV_{m0}^a)^m}{m-1} - \frac{(aV_{m0}^a)^m}{m+1} - (V_{m0}^a + V_{a0}) \right] \right\}, \tag{9} \]

\[ \omega_n B_{n0} = -\frac{F_n(a)}{R} \frac{B_{n0}}{V_{a0}} - \frac{ic^3 m}{4\pi a} \left[ i(a^2 B_{n0}^a)^2 + mB_{n0}^a \right]. \tag{10} \]

In Eqs. (8) - (10) \( F_n(a) = m\mu(a)/n, S = a d^q, q \)

\[ B_{n0} = \frac{c^2}{R} F_n(a), \quad c^2 = \gamma_0 \rho_0 / \rho_0, \]

\[ \Omega_n^2(a) = \omega_n, \omega_n = \frac{\omega}{B_{n0} F_n(a) V_{a0}} + \frac{B_{n0} m c}{B_{n0} a E_{n0}}, \quad \omega_n = \frac{\omega - \frac{B_{n0} F_n(a)}{B_{n0}} V_{a0}}{m^2 \left[ \frac{P_{n0}}{\rho_0^2} - c \frac{E_{n0}}{E_{n0}} \right]} \]

In our consideration all poloidal harmonic amplitudes of perturbations have finite values. The number of poloidal harmonics with finite values of amplitudes depends on the antenna spectrum (external perturbation). Equilibrium parameters are denoted by the subscript 0. We took into account the equilibrium poloidal plasma rotation due to the existence of an equilibrium radial electric field \( E_{0a} \), the ion diamagnetic drift and the parallel with respect to equilibrium magnetic field plasma rotation with a velocity \( V_{0l} \).

Fig. 1. Equilibrium pressure gradients (in Pa)

For simplicity we consider case \( c_s = 0 \) and \( \omega = 0 \). Near the plasma edge the inequality \( S^2 \gg 1 \) (\( S \sim 4 \)) takes place. From Eqs. (8) - (10) we get in this case

\[ p_n = -\frac{ipV_{a0}^a}{\omega_n} = \frac{i p R}{F_n(a) B_{n0}} \left[ B_{n0}^2 + \frac{i c^2 m}{4\pi a} \right] \left[ i(a^2 B_{n0}^a)^2 + mB_{n0}^a \right], \tag{14} \]

\[ \frac{1}{a_n} \frac{d}{da_n} \left( a_n d(a_n V_{a0}) \right) = \frac{m^2}{a_n} (a_n V_{a0}^a) - m \frac{m}{a_n} Q_n(a_n V_{a0}^a) = 0, \tag{15} \]

where

\[ K_n(a_n) = \frac{\left( m K_n(a_n) F_n^2(a_n) + B_{n0}^2 A(a_n) \right)}{4\pi a_n}, \tag{16} \]

\[ K_n(a_n) = \frac{F_n(a_n) a F_{n0}}{R mc} \left[ \frac{1}{B_{n0}} \frac{d}{da_n} \frac{T(a_n)}{a_n^2} - E_{n0}(a_n) \right], \tag{17} \]

\[ A(a_n) = \frac{8\pi}{B_{n0}^2} a_n \frac{d}{da_n} \left( m^2 (\mu^2 - 1) \frac{R S_{n0}^2}{a} \right), \tag{18} \]

The pressure perturbation resonant excitation by external low frequency helical magnetic perturbations near the plasma edge is possible when \( F_n(a_n) \approx 0 \) or \( K_n(a_n) \approx 0 \) (Eq. (19)). The case \( K_n(a_n) \approx 0 \) occurs during the plasma rotation only. It may affect the excitation of ballooning and peeling modes because of a plasma pressure change. In Figs. 1, 2 the behaviors of the equilibrium pressure gradients and equilibrium radial electric field \( E_{0a} \) are shown for typical DIII-D

2. DISCUSSIONS

Poloidal modes \( m = 9...14 \) and toroidal mode \( n = 3 \) are considered. The profile \( q(\psi) \) near plasma edge close to the DIII-D experiments is used ([3, 4]). From Eqs. (14), (15) the pressure perturbation is presented in the next form:

\[ p_n = \frac{m K_n(a_n) F_n^2(a_n)}{4\pi a_n} \left[ A(a_n) \right] \left( \frac{c}{4\pi a_n} \right), \tag{19} \]
In Fig. 3 and Fig. 4 the radial profiles of $\text{Re}Q_m$ and $\text{Im}Q_m$ are shown, respectively ($m = 11$). Here $B_{\phi 0} > 0$. If $V_0 = 0$ the strong change in profile of $Q_m(a_0)$ is visible near $a_0 \approx 0.948$ where $F_{11}(a_0) = 0$ only. And effect of the resonance $K_m(a_0) \approx 0$ at $a_0 \approx 0.958$ is small. When $V_0 \neq 0$ the effect of the resonance $K_m(a_0) \approx 0$ at $a_0 \approx 0.958$ is strong and depends on direction of rotation. Note that the position of this resonance does not depend on $m$ practically. But position of $F_{m}(a_0) \approx 0$ resonance depends on $m$ strongly.

**CONCLUSIONS**

The strong influence of toroidal plasma rotation on pressure perturbation resonant excitation by external low frequency helical magnetic perturbations near the plasma edge is shown. The plasma rotation and plasma response play a key role in this phenomenon.

**REFERENCES**


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Obtained results may be used to control of the plasma stability for experiments in tokamaks JET, DIII-D, TEXTOR and future ITER operation.