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Force Free State for Tokamak Plasmas

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The gyrokientic MHD equations associated with the gyrokinetic electromagnetic Vlasov-Maxwell system [1] can be written as

$$\left(\frac{\partial}{\partial t} - \frac{c}{B}\nabla\phi \times \mathbf{b}\cdot\nabla\right)\nabla_\perp^2\phi - 4\pi\frac{v_A^2}{c^2}\nabla\cdot(\mathbf{J}_\parallel + \mathbf{J}_\perp) = 0 \tag{1}$$

for the vorticity equation, and

$$E_\parallel \equiv -\frac{1}{c}\frac{\partial A_\parallel}{\partial t} - \mathbf{b}\cdot\nabla\phi \approx 0, \tag{2}$$

for the parallel Ohm's law, where $\mathbf{J}_\parallel$ is given by the parallel Amperes' law,

$$\nabla^2 A_\parallel = -\frac{4\pi}{c}J_\parallel, \tag{3}$$

and the finite-Larmor-radius (FLR) modified ion perpendicular pressure balance [1] becomes

$$\mathbf{J}_\perp \approx \frac{c}{B}\hat{\mathbf{b}} \times (\nabla p_i)\left[1 - \frac{1}{2}\rho_i^2\frac{\nabla_\perp^2 p_i}{p_i}\right]. \tag{4}$$

The modification of the poloidal current, $\mathbf{J}_\perp$, is the result of the radial electric field of the form [2,3],

$$enE = \frac{1}{2}\nabla_\perp p_i. \tag{5}$$

If

$$\nabla p_i \approx 0$$

or

$$p_i \propto exp(-\sqrt{2}r/\rho_i),$$

the poloidal current, $\mathbf{J}_\perp$, vanishes and we reach a force-free steady state with shear Alfven waves as normal modes. The relationship between the H-mode in tokamak plasmas and the force free state will be discussed.

[1] W. W. Lee, Phys. Plasmas, **23**, 070705 (2016).

[2] W. W. Lee and R. B. White, Phys. Plasmas **24**, 081204 (2017).

[3] W. W. Lee and R. B. White, Phys. Plasmas **25**, 054702 (2018).