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Scaling law of the plasma rotation in visco-resistive magnetohydrodynamic systems

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The rotation of plasma has been identified as a possible key factor in the heat and particle confinement properties in tokamaks. Numerous experimental observations have supported the existence of intrinsic plasma rotation in connection with the high-confinement mode [1]. One option to avoid instabilities could be to make plasma rotate to stabilize it. The understanding and control of plasma rotation are of utmost importance for achieving enhanced plasma performance and sustainable fusion reactions in tokamak devices.

The usual approach begins by using the axisymmetric Grad-Shafranov equation at zeroth order to reconstruct magnetic flux surfaces in real-time. In this context, any existing velocity field is considered to be primarily the result of “turbulence”, including its axisymmetric part. It means that in the usual approach there is no steady-state plasma velocity: an equilibrium plasma is a non-rotation plasma.

The present approach follows Montgomery's works [2]. To address this matter, we conduct numerical computations of the steady-state Navier-Stokes equation, which includes the non-linear $(\boldsymbol{v}\cdot\boldsymbol{grad})\boldsymbol{v}$ term [3, 4, 5]. To obtain a closed system of partial differential equations we solve it on the cross-section plasma domain Ω together with Maxwell equations, Ohm's law and boundary conditions [6, 7]. We numerically compute the axisymmetric steady states of the visco-resistive magnetohydrodynamic equations using the finite element method through the open-source platform FreeFem++ for solving partial differential equations [8].

By considering a visco-resistive magnetohydrodynamic model for a tokamak plasma with a given toroidal current drive, we predict and numerically check a scaling law of the toroidal velocity as the function of the resistivity, η, and the Hartmann number $H \equiv (\eta\nu)^{-1/2}$. This scaling law is $\{v_\varphi\}_{rms} \simeq \eta f(H)$ for some function f and should be valid as long as the inertial term remains negligible. Then, we reconsider this in light of the possible anisotropy of plasma resistivity and argue that the perpendicular resistivity can be retained in this scaling.

References

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