Linear Theory of Viscous-Resistive Tearing Instability

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$$\phi'''' = (\kappa\epsilon^2/\nu)((\lambda+\nu\kappa)(\phi''-\kappa^2\epsilon^2\phi)+\lambda\kappa f(\xi)\psi-\kappa f^2(\xi)\phi-f''(\xi)\psi), \quad (1)$$

$$\phi''-\kappa^2\epsilon^2\phi = -\kappa f(\xi)\psi+\kappa f^2(\xi)\phi/\lambda+f''(\xi)\psi/\lambda, \quad (2)$$

$$\psi''-\kappa^2\epsilon^2\psi = \kappa\lambda\psi-\kappa f(\xi)\phi. \quad (3)$$

Magnetic reconnection process is believed to play a crucial role for explosive phenomena of space plasma, such as solar flares and substorms. In past 60 years, tearing instability has been widely examined to explore the beginning of the magnetic reconnection, i.e., linear growth stage.

In this paper, the non-viscous linear theory (eqs.(2)&(3)) of tearing instability, which was introduced by Loureiro (Phys.Plasmas, 2007) and then modified by author (Asia-Pacific Conf. on Plasma Phys 2018), is extended to viscous resistive MHD (eq.(1)&(3)). The perturbation equations of eqs.(2) and (3) are based on non-viscous resistive MHD, but more realistic tearing instability must be based on viscous resistive MHD, where eq.(2) is replaced by (1) with uniform viscosity coefficient ν. It is the most important that eq.(1) must be applied only for ξ<ξo, and hence, eq.(2) is applied for ξ>ξo, to rigorously keep the equilibrium f(ξ) introduced by Loureiro. In other words, the inner region of current sheet is solved as viscous resistive MHD (ν=const), and the outer is solved as non-viscous resistive MHD (ν=0). Following Loureiro's notations, Φ and Ψ are the potential functions of, respectively, flow and magnetic fields, where k, ε, λ, and f(ξ) are the wave number of plasmoid chain, uniform resistivity, linear growth rate, and equilibrium magnetic field function. Note that λ normalized by the Alfven time scale cannot exceed unity for tearing instability. The derivative is with respect to ξ space taken as the normal direction to the current sheet. In this paper, Φ and Ψ are numerically solved as the initial value problem starting from ξ=0 with Φ (0)=0, Ψ(0)=1, and Ψ'(0)=Φ'' (0)=0 for the symmetricity at ξ=0. To uniquely specify the solution, let us additionally assume the continuity of Φ' at ξ= ξo, which compensates the discontinuity of f''(ξo) and ν. Then, Φ'(0), Φ'''(0), k, ε(=e), and λ are the adjustable parameters for the parameter survey of initial value problem. Adjusting those parameters, let us find Φ (ξc)=Ψ (ξc)=0 at a given ξc value. Let us call ξc the crossing point. Fig.1 shows a typical solution obtained for ξc =7.2 with k=1, ε=0.2, λ=0.429, ν=0.001, Φ'(0)=1.66163, and Φ'''(0)=-5.41347.

Fig.2 shows the λ change for ν for 0.002<e<0.3, where λ tends to decrease for larger ν. This feature appears to be reasonable for viscosity effect. The magnetic Prandtl number is *Pm*=ν/e, but it must be noted that the spatial scale ξ is normalized by the thickness of current sheet, and hence, is changed by e. In Fig.2, the case of ν >1 is not shown, because the numerical convergence is not rigorously confirmed, but λ appears to be constant for larger ν. Meanwhile, as ν goes to zero, λ reasonably tends to approach the growth rate obtained from eqs.(2) and (3), i.e. fully non-viscous case. As *Pm* is close to zero, the tendency of approach is clear even for larger ν.

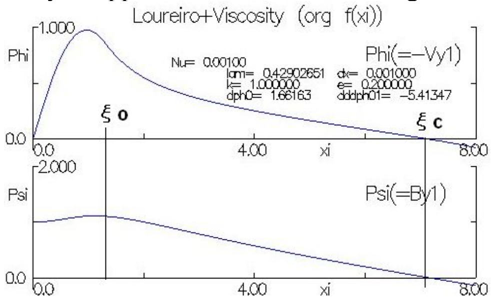

Fig.1: Zero-crossing Φ and Ψ at ξc =7.2.

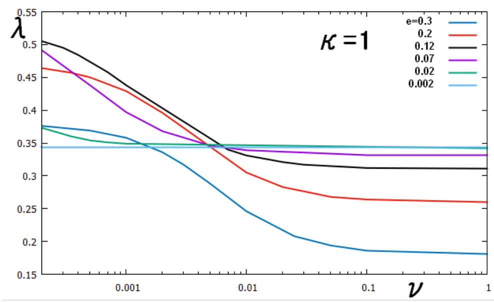

Fig.2: Growth rate change for ν and various e(=ε).

References :

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