Effects of Turbulence Induced Viscosity and Plasma Flow on Resistive Wall Mode Stability

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Abstract. In this paper, we investigate the effects of a new dissipation mechanism, turbulence induced viscosity, on the resistive wall mode (RWM) stability. The eigenmode equation for RWM is derived, including the turbulence induced viscosity and the plasma flow. The test computations are carried out to study the dependence of the mode growth rate on the wall conductivity, for a case without the viscosities and the plasma flow. With the turbulence induced viscosity but without flow, the numerical results show that the growth rate of the RWM decreases quickly with enhancement of the turbulent viscosity. In the presence of the plasma flow, the results show that the RWM is completely suppressed when the plasma rotation frequency exceeds a critical value. Especially, the numerical results show that the turbulent viscosity significantly reduces the threshold of flow velocity required for the RWM stabilization. The effect of the turbulent viscosity on the stability window, in terms of the wall minor radius, has also been investigated.

1. Introduction

The stabilization of large-scale magneto-hydrodynamic (MHD) modes is necessary for the magnetic confinement of toroidal plasma such as the International Thermonuclear Experimental Reactor (ITER). In tokamaks, the maximum achievable value of the parameter $\beta (=2\mu_0 P / B^2$, the ratio of the plasma pressure to the magnetic field pressure) is often limited by the external kink modes, which can be stabilized by placing a perfectly conducting wall sufficiently close to the edge of the plasma. However, the wall of the actual tokamaks has finite conductivity. This converts the external kink mode into a slowly growing MHD mode which is called as the resistive wall mode (RWM). The RWM instability can be driven by the pressure gradient and the current gradient of the plasma. In this study, we investigate the behaviors of the RWM driven by the current gradient of the plasma.

As for the stabilization of the RWM in tokamak plasma, two approaches are investigated extensively during recent years, namely rotational stabilization [1-5] and feedback control [6-10]. It has been shown, both in theories and experiments, that the RWM can be completely suppressed by the toroidal plasma rotation, provided that the rotation velocity exceed a certain threshold value, which is typically a few percent of the Alfvén wave speed at the plasma centre. And the threshold rotation speed is rather sensitive to the damping model [10]. The physics mechanisms of the rotational stabilization of the RWM have not been fully understood. For example, the present MHD theory can not explain the recent experimental results [11, 12] clearly, which show that RWM can be stabilized with very slow toroidal rotation speed. Understanding the damping mechanism of the RWM is crucial not only for studying the critical rotation speed required to stabilize RWM in tokamak plasmas but also for understanding other related physics such as the plasma momentum damping.

In this study, we developed a cylindrical model including turbulent viscosity, which is related to the gradients of the magnetic field fluctuation and the plasma flow fluctuation in the plasma, and applied this model to study the RWM stability in tokamak plasma. The effects of the turbulent viscosity are incorporated into the model via a viscosity term $\chi$ in the momentum equation. Authors of Ref. [13] have demonstrated that the role $\chi$ plays in the