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Numerical Analysis of Instability of M-shape Flux Rope in the Solar Corona

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The stability of magnetic flux rope in the solar corona is an important issue to understand the onset mechanism of solar flares and the formation of coronal mass ejections (CMEs). The instability of axisymmetric flux rope, called torus instability, is proposed to be the primary driver of solar eruption by Kliem and Toeroek (2006). They analyzed the ideal magnetohydrodynamic (MHD) stability of toroidal electric current channel for the mode of self-similar expansion, and concluded that the decay index of environmental magnetic field determines the criterion of the instability. However, several observations suggested that flux rope forms a non-axisymmetric loop in pre-eruptive state. In particular, the flux rope of M-shape structure, in which magnetic field line is concave above a magnetic polarity inversion line, is thought to be related to the onset of solar eruption. For instance, Moore et al. (2001) explained how the M-shape flux rope can be formed and erupts by tether-cutting reconnection. Recently, Kusano et al. (2012) found that the pre-flare reconnection between the sheared arcade and the small-scale magnetic flux of typical orientations favors the formation of M-shape flux rope and well triggers the tether-cutting reconnection scenario. However, the critical condition for the instability of the M-shape flux rope is still unclear.

In this paper, we numerically study the stability and dynamics of the M-shape flux rope. We model the M-shape flux rope using two current carrying tori which connect each other above the polarity inversion line and are anchored on the solar surface. The equilibrium condition is derived from the force balance of the hoop force of tori and the Lorentz force acting from external magnetic field. We also solve the equation of motion for the altitude of magnetic dip under the constraint that magnetic flux across the flux rope is conserved. As a result, the M-shape flux rope can be destabilized if the intensity of electric current exceeds the criterion and the altitude of magnetic dip ascends to the critical height. The numerical solution indicates that the decay index at the critical height of magnetic dip is substantially lower than the criterion of axisymmetric torus instability. It suggests that the M-shape flux rope much easily erupt than the theoretical prediction of axisymmetric torus instability, and the filament eruption may start even from a lower potion where the decay index is lower than the conventional criterion.

Keywords: Sun, instability, flare, CME