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A physics model of the rotating halo current during VDE disruption

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Disruption in the TOKAMAK device is generally known as one of the most harmful events. The subsequent event of the thermal quench and the current quench cause collateral heat-damage and structural damages. These two potential sources of danger are relatively well known because it is easy to conceive that the confined thermal energy and the magnetic field energy associated with the plasma current in the tokamak system are pouring out at the disruption event. The magnetic energy associated with the plasma current induces the eddy and the direct contact of the plasma current to the surrounding wall causes halo. Both currents flowing through the tokamak structure unleash huge JxB forces which can deteriorate the structural solidity of the machine. In addition to the direct JxB forces by eddy and halo current with the toroidal magnetic field, there is a relatively unknown harm source. Especially during the disruption followed by the vertical movement (VDE), several devices reported the toroidally rotating halo current and were projected toward ITER by multi-machine scaling [Myers 2018]. The biggest concern of the rotating halo current is that one of the vibration modes of machine structure might resonate with the rotating frequency of halo current. Likewise, other tokamaks referred to in C.E.Myer's paper, KSTAR also showed the same phenomena. Figure 1 shows the typical observation of the rotating halo current.

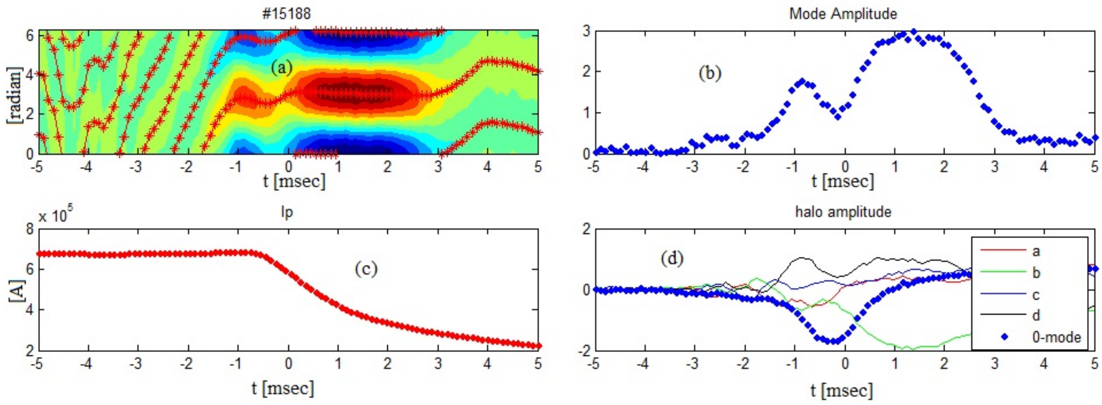

Figure 1: Toroidal amplitude of n=1 asymmetric halo current (a), Amplitude of the n=1 mode (b), the Plasma current (c), and the halo currents measured by four toroidal sensors on the bottom side (d). All figures are on the same timeline and the time where dIp/dt has the maximum value set to be t = 0.

The dynamics of the halo current observed in KSTAR is complicated. The direction of the rotation changes shot to shot and also during a shot implying that it is not caused by the MHD mode riding on the rotating plasma. KSTAR plasma rotates fast and it is not comparable with the slow halo rotation and its direction is always co-current especially for the H-mode plasma. How can it rotates opposite to the plasma rotation and why its speed is far low than plasma rotation should be explained. Even though the projection to ITER is urgent it seems there is no relevant explanation of the relatively low rotation frequency and direction changes so far. Through data analysis of the KSTAR disruption event from 2015 to 2018, we found ample examples of the rotating halo current changing its direction during a shot. We propose a new physics model that elucidating the dynamics of frequency and the change of the rotation direction of the halo current. The model is assuming that the tokamak plasma can be regarded as a spinning rigid body and its angular momentum tilted during an abrupt VDE event for some reason. Then the external torque exerted on the plasma results in a precession motion of the toroidal plasma likewise a tilted spinning top. Depending on the external torque whether it tends to stand upright the spinning top or tilt it more, the precession direction could be changed. The main sources of the external torque are the magnetic field by PF coil currents and the induced current on the passive plate. Two torque compete and the stronger one determines the precession direction. As the plasma approaches the passive plate during a VDE event, the induced current on the passive plate dominates the PF coil effects. Figure 2 shows the external torques by the PF coils and the induced current as the plasma moves downward.

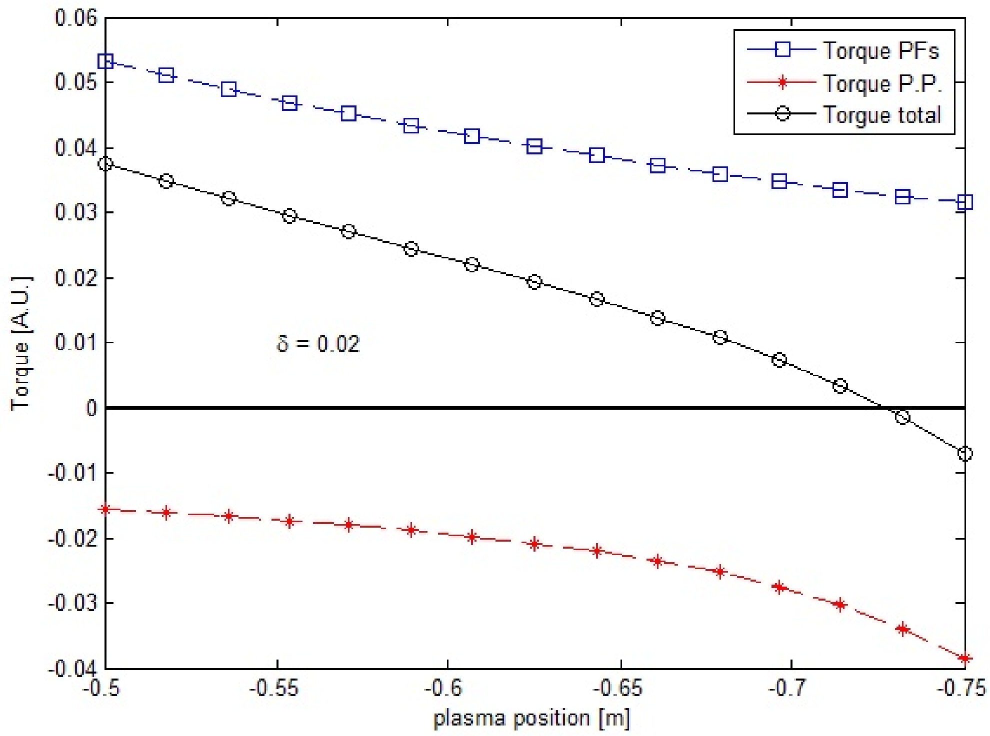

Figure 2: The blue line with the square box is the torque by the PF coils, the red line with the asterisk is the torque by the induced current on the passive plate, and the black line with the circle is the sum of two torques. The δ= 0.02 means tilting angle of the plasma angular momentum from the vertical axis in the radian unit.

The precession of the plasma torus makes the rotation of the contact point of the plasma with the wall and it results in a rotation of the halo current. The complicated dynamics of the rotation speed and direction variance during the VDE would be discussed in this paper with a detailed explanation of the model. Also, the statistical analysis of the KSTAR data based on this model for the recent experiments will be presented.

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