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Current sharing between plasma and walls in tokamak disruptions

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Plasma disruptions in tokamaks represent a significant obstacle in enhancing performance of the plasma regime. In the next step machines, such as ITER, disruptions impose very challenging requirements on the design of the structural elements of the machine and its in-vessel components. Although, regarding the global forces due to disruptions on the vacuum vessel there is sufficient certainty because of explicit scalings, e.g., from JET to ITER, many important aspects of plasma interaction with the plasma facing components (localization of forces, their impulse, rotation, etc) require additional consideration.

Here, the new aspects of electric current sharing between plasma and the wall during vertical disruption events (VDE) will be presented. Typically, the currents to the plasma facing tiles are associated with the so-called “halo” currents, which flow along the open field lines outside the plasma edge (the last closed magnetic surface). These currents are distributed in space and by themselves are not of concern. It is their continuation into the vessel walls that can create substantial forces, which are already studied.

Recently [1], it was understood that completely different currents play the major role in VDEs [2]. Called the “Hiro” currents, they are excited by the instability, which moves the plasma into the resistive wall. In the case of the vertical instability $n = 0$ the Hiro currents flow along the tiles surface while the plasma itself shorts out the electric circuit between tiles. In the presence of the kink mode $m/n = 1/1$, mixed with the vertical instability, the plasma contact represents a localized zone on the wall surface, and the Hiro currents become the continuation of the edge currents on the free plasma surface.

The effect of the Hiro currents might be significant for the ITER plasma facing beryllium tiles. Unlike the eddy currents, which are localized in each tile and are negligible in amplitude, the Hiro currents have a global character. Their amplitude is determined by the plasma displacement. The instability acts as a current generator which maintains the necessary level of Hiro current independent of resistivity of the electrical circuit in which they flow. As a result, significant forces (both vertical and sideways) can be applied to the tiles themselves. Also, the edges of the tiles can be potentially damaged by the significant Hiro currents flowing between tiles.

The theoretical analysis and numerical simulations of this effect, earlier not considered, will be presented. The 2D version of a disruption simulation code (DSC), operational already, can already simulate some aspects of the Hiro currents. DSC is now under extension to the 3D case for the appropriate description of the plasma-wall contact. The electromagnetic model based on the current ITER design of the plasma facing tiles will be used in simulations.

In addition to the effects of Hiro currents, which are directed opposite to the plasma current, MHD instabilities generate surface currents (a counterpart of the Hiro currents) in the same direction as the plasma current. These currents, localized at the plasma edge, can flow to the plasma facing surface of the tiles, and potentially can provide the alternative to the present “halo current” interpretation of the tile current measurements during disruptions in tokamaks. The simulations of the vertical instability, which describe the effect of these tile currents (referred to as Todd Evans currents) on plasma dynamics will be presented and potentially compared with the measurements on the EAST machine using specially designed tiles for both Hiro and Todd Evans currents measurements.

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