Current flows towards the divertor during VDEs at COMPASS

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Introduction. Consistent theoretical understanding of current flows to the vacuum vessel (VV) and their paths in the wall during disruptions is essential for electromagnetic loads estimation when designing future machines such as ITER [1]. A number of models including "source and sink" [2], Hiro currents [3] and Asymmetric Toroidal Eddy currents (ATEC) [4] focus on plasma-vessel electromagnetic interaction. The aim of this work is to test ATEC model that predicts that toroidal currents between plasma facing components (short-circuited through the plasma) can significantly modify the current flow path between the plasma and the vacuum vessel and thus the resulting forces by VDEs.

Special divertor tiles. Two special divertor tiles (Fig. 1) were installed at the COMPASS tokamak [5] in order to investigate, whether part of the toroidal addy current can flow to the divertor tiles and through the gaps between them forming a parallel current circuit. The tiles are toroidally separated by 135°. The tiles have identical design consisting of 8 segments (their labels are shown in Fig. 1 (a, b)). The segments are insulated from the VV by Boron-Nitride backplate. Three pairs of segments have 2.5 mm gap between them. These toroidally split segments measure current flows from the plasma to the VV by Rogowski coils located outside of the VV. The signal difference between left and right segments of each pair allows interpretation of halo and eddy currents paths.

Current flows towards divertor. Current flows were measured during a dedicated campaign having 37 downward disruptions (in the direction of the divertor). The discharge parameters were kept unchanged ($I_p = 300kA$) with the exception of I_p direction which was reversed for some discharges. In addition to this, the tiles are left in the VV vessel until the end of COMPASS operation and regularly perform measurement during unintentional disruptions. The tiles' segments have 4 possible connection configurations (Fig. 2): grounded (cable leading from the segment is grounded to the VV on the feedthrough outside of the VV), floating (left and right segments are connected to each other with no contact to the VV), disconnected (the segment has no connection to the VV nor to the neighboring segments) and cross-floating (LFS left segment

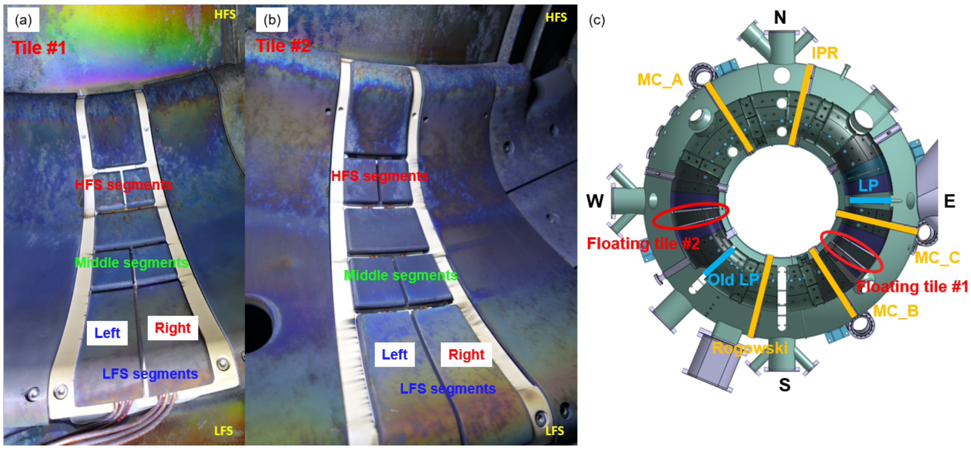

Figure 1: *(a) Tile #1. Measuring pairs of segments are labeled as High Field Side (HFS), Middle and Low Field Side (LFS) according to their position in the VV. "Left" and "Right" notation is used to distinguish the segments in each pair; (b) Tile #2; (c) Tiles' toroidal position and accompanying diagnostics: I_p measurement by full Rogowski coil, 3 rings of Mirnov coils (MC_A, MC_B and MC_C) and Internal Partial Rogowski coils (IPR); Plasma-wall contact point position by divertor Langmuir probes (LP and Old LP).*

is connected to the Middle right segment and LFS right segment is connected to Middle left one).

Typical signal in grounded configuration is shown in Fig. 3. HFS segments have positive signals, while Middle and LFS are negative due to the halo current direction. Halo current flows along open magnetic field lines and then closes its path through the VV. For standard toroidal field (B_t) direction it flows inside the VV on the HFS and flows out of the VV on the LFS. Significant asymmetry is observed between left and right neighboring segments. It is suspected that this might be due to eddy currents partially flowing to the divertor tiles and short-circuiting the gaps between them as schematically shown in Fig. 2(a). In this case left segment would measure $I_{\mathrm{L}} = I_{\mathrm{halo}} + I_{\mathrm{eddy}}$ while the right segment $I_{\mathrm{R}} = I_{\mathrm{halo}} - I_{\mathrm{eddy}}$. Therefore, the asymmetry is expected to be dependent on eddy current direction which can be changed by I_p reversal. It was observed that I_{R} becomes larger than I_{L} at reversed I_p, which is consistent with ATEC model predictions of gaps short-circuiting.

Current flows in floating configuration are shown in Fig. 4. According to ATEC model the current should flow in co-I_p direction when the segments are connected to each other. LFS and HFS segments signals confirm this hypothesis, also changing the current direction after I_p reversal. Middle segments are not discussed here, as they are located in the vicinity of plasma-wall contact point where magnetic field lines have very shallow incident angle. Therefore, small misalignment or shadowing of the segments will result in significantly asymmetrical wetted area and halo currents. HFS and LFS segments are not prone to this effect.

Cross-floating configuration aims to distinguish contributions from halo and eddy currents. As can be seen from Fig. 2(b), the current should flow from the Middle to the LFS segments if halo contribution is dominant. In case of dominant eddy currents, current flow from right to left segment is expected at standard I_p. Experimental results shown in Fig. 5 indicate that the segments measure primarily halo currents. However, the current magnitude from the Middle left to the LFS right segment is smaller than the one from the Middle right to the LFS left segment. This might be due to eddy current contribution as expected from ATEC model. The asymmetry reverses with I_p reversal for Tile #1, but the dependence is not clear for Tile #2. It should be taken into account that the Middle segments might have non-uniform halo current and affect the asymmetry.

Additional measurement were performed during dedicated VDE experiments. Divertor Langmuir probes [6] allow estimation of plasma-wall contact point position. The tile were observed by two fast visible cameras. Both diagnostics show significant 3D asymmetry of the plasma that might affect the ration of the asymmetry between left and right segments.

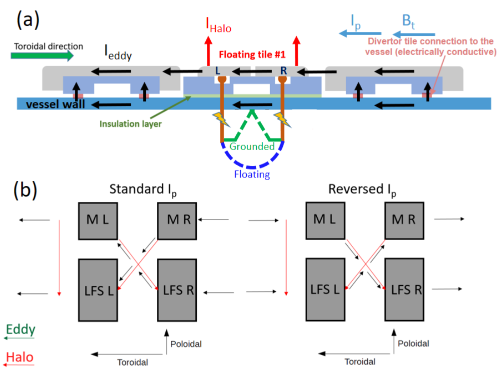

Figure 2: *(a) Tiles segments' connection configurations: grounded and floating (green and blue dashed lines). Eddy current flow according to ATEC and halo current (black and red arrows) are shown at LFS segments for standard I_p and B_t direction; (b) cross-floating segments connection and related halo and eddy currents flows (red and black arrows) shown for standard and reversed I_p direction.*

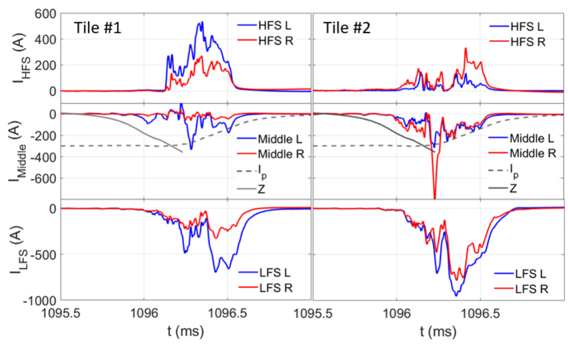

Figure 3: *Current flows to the divertor tiles in grounded configuration during disruption. From top to bottom: HFS, Middle and LFS segments of tile #1 (left column) and tile #1 (right column). Left and right segments are indicated by blue and red curves.*

Conclusions. Current flows towards the special divertor tiles were measured during VDEs. The current flow reaches 2 kA in discharges with $I_p = 300kA$, but may vary from discharge

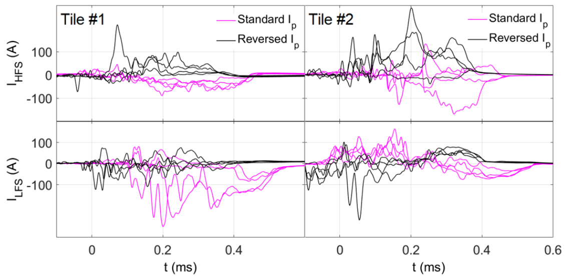

Figure 4: *Current flows to the left segment in floating configuration for tile #1 (left column) and tile #2 (right column). Signals at standard and reversed direction of I_p are represented by magenta and black curves. Negative signal correspond to the current flowing towards the segment.*

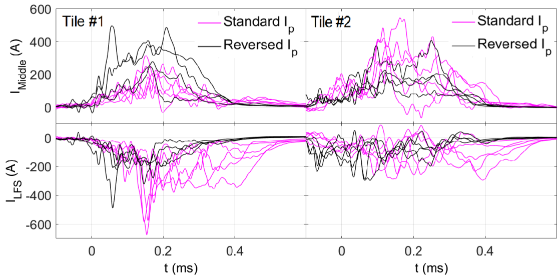

Figure 5: *Current flows to the left segment in cross-floating configuration for tile #1 (left column) and tile #2 (right column). Signals at standard and reversed direction of I_p are represented by magenta and black curves. Negative signal correspond to the current flowing towards the segment.*

to discharge with similar plasma parameters. Both tiles exhibit a certain pattern of asymmetry between neighboring left and right segments. The asymmetry dependence on I_p direction is consistent with ATEC model prediction in most cases in grounded, floating and cross-floating configurations. However, it is not clear yet why the two identical tiles consistently show an opposite behavior in terms of left and right segments ratio. In addition to this, some outliers non-consistent with ATEC model are present. A possible explanation could be a strong 3D asymmetry of the plasma during disruptions, that is detected by additional measurements including contact point position and fast camera videos.

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