Statistical analysis of disruptions in COMPASS

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Introduction

Understanding of disruptions plays an important role for a design of the future fusion devices as they induce large thermal and mechanical loads on a vacuum vessel [1, 2]. Statistical analysis of the set of discharges during the period of April 2014 – December 2017 was performed in order to improve our knowledge of disruptions on COMPASS. About 58 % of COMPASS plasma discharges are disruptive which provides a good opportunity for disruption studies. Fig. 1 represents operational space of the machine and indicates regions where disruptions are likely to occur using so-called disruptivity. Disruptivity is defined as the number of disruptions observed in a certain plasma state divided by total plasma operation time spent in this state.

Current quench

Fast plasma current decay during disruptions induces eddy currents which might cause severe damage to the vacuum vessel. Current quench time (CQT) is estimated as an interval where plasma current decays from 80% to 20% of predisruption current I_{disr}. Instantaneous current quench rate (CQR) is evaluated using the mean value of the time derivative dI_p/dt during the interval of CQT. CQR increases with predisruption current to I_{disr}<350 kA and then saturates. Fig. 2 shows CQR and CQT normalized to poloidal plasma area prior to disruption. Normalized CQT lower limit is about 1.7 ms/m^2 which agrees with results observed at other tokamaks [7]. However, there are several outlier discharges detected during Runaway Electron (RE) campaigns. They exhibit extremely high CQR (up to 8 MA/ms) and normalized CQT below 1.7 ms/m^2.

Asymmetrical disruptions

Asymmetrical disruptions are of particular concern because they induce additional currents and, therefore, forces in the vacuum vessel [3, 4]. In addition to this they might lead to a resonant amplification of the forces. The COMPASS tokamak is equipped with magnetic diagnostics, which allow measurements of the plasma current I_p at five toroidal locations (Fig. 3). This enables detailed investigation of asymmetrical disruptions (almost 87 % of flat-top disruptive discharges on COMPASS). Fig. 5 presents two typical asymmetrical disruptions at COMPASS.

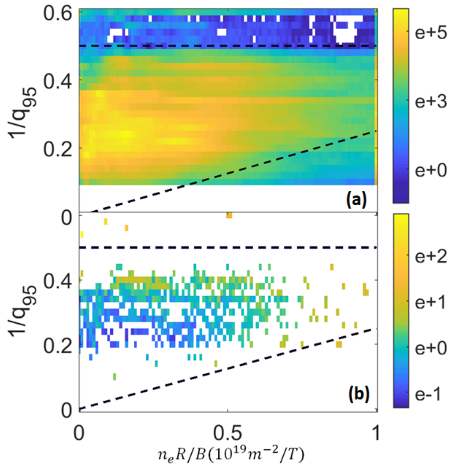

Figure 1: *(a) Hugill diagram for the operations of COMPASS between April 2014 and December 2017. Discharges are sampled at 20kHz, when plasma current is larger than 30 kA. Logarithmic scale is used. (b) Hugill diagram for disruptivity. Dashed lines represent plasma current and density operational limits.*

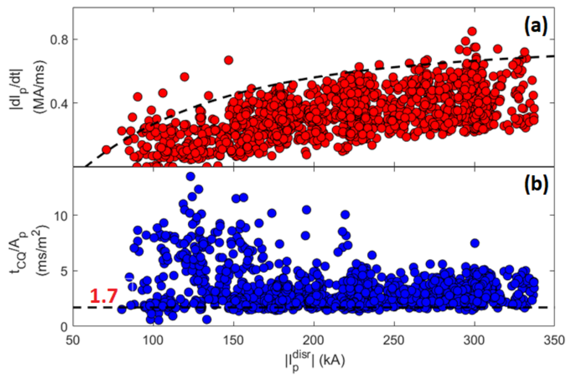

Figure 2: *(a) Instantaneous current quench rate versus predisruptive plasma current. (b) Current quench time normalized by poloidal plasma area versus predisruptive plasma current.*

Rectangular smoothing ± 0.05 ms is applied to the measured I_p. Normalized asymmetry magnitude is determined as $A_p^{asym} = I_p^{asym}/I_p^{disr} \cdot 100\%$. The interval where A_p^{asym}>2% is called asymmetry window ΔT, the data is trimmed everywhere else. Time integrated asymmetry is defined as $A = \int_{\Delta T} A_p^{asym} dt$. Number of asymmetry rotations and rotational frequency can be determined using $N_{turn} = (\phi_{max} - \phi_{min})/2\pi$ and $f = N_{turn}/\Delta T$ respectively.

Typical magnitude of plasma current asymmetry at COMPASS is 8% of I_p^{disr}. Asymmetry rotates in both clockwise and anticlockwise directions with 0-5 turns. However, multirotational asymmetry is observed only in the direction opposite to the negative plasma current (Fig. 7). The effect has been reported at JET [6], but its nature is not clear yet. Asymmetry rotational frequency decreases with plasma current (same observed at JET [6]).

Asymmetric Toroidal Eddy Currents (ATEC) model [5] provides an explanation of plasma current asymmetry detection on various tokamaks. According to ATEC gaps between tiles might be short-circuited upon plasma contact and part of the vessel current might flow through the tile. In case a diagnostic coil is located behind the tile, there is a possibility that part of the vessel current is falsely detected as plasma current leading to an asymmetry effect. COMPASS magnetic diagnostics coils are covered by plates in the bottom part of the vessel, they are located behind the gap between limiter tiles on the high field side (HFS) (Fig. 4) and they are not covered by any structures in the upper side. Therefore, it is expected that the largest plasma current asymmetries should be observed for the disruptions with plasma moving towards the HFS. However, experimental results show no evidence on the plasma current asymmetry magnitude dependence on the disruption direction (Fig. 6).

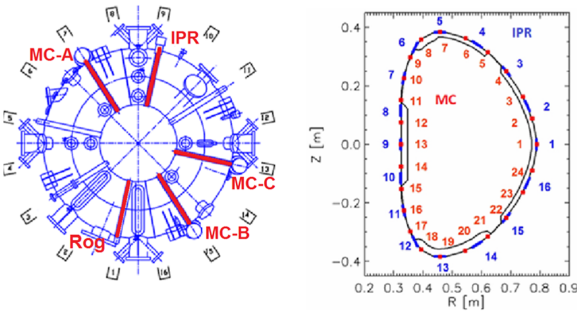

Figure 3: *COMPASS tokamak magnetic diagnostics. Internal partial Rogowski coils (16 coils) (IPR), Rogowski coil (Rog), 3 rings of Mirnov coils (24 coils each) (MC-A, MC-B, MC-C).*

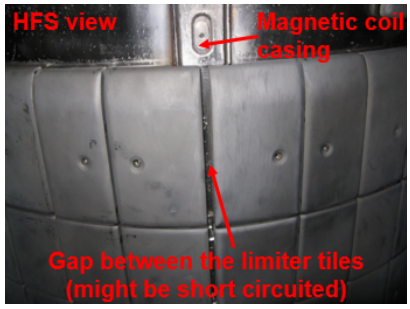

Figure 4: *COMPASS magnetic diagnostics coils location in the vacuum vessel (HFS view).*

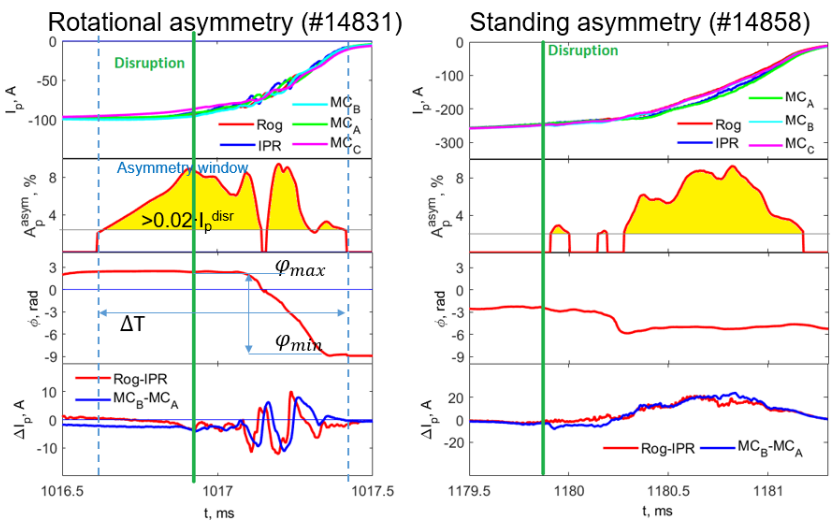

Figure 5: *Plasma current asymmetry during disruption: (a) rotational (#14831) (b) standing (#14831). The traces are as follows, from top to bottom: plasma current measured at 5 toroidal locations; plasma current asymmetry magnitude; asymmetry phase; plasma current difference between two opposite* (180°) *toroidal locations.*

Conclusions and future plans

It has been reported that RE discharges might result in an extremely fast current quench (up to 8MA/ms for COMPASS). There is no evidence that plasma current asymmetry is caused by

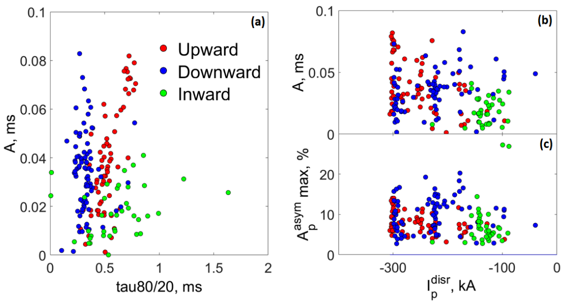

Figure 6: *(a) Normalized asymmetry magnitude versus CQT. Upward, downward and inward (HFS) directions of disruption are marked with red, blue and green colors. (b) Normalized asymmetry magnitude versus current (c) instantaneous maximum normalized asymmetry magnitude versus current.*

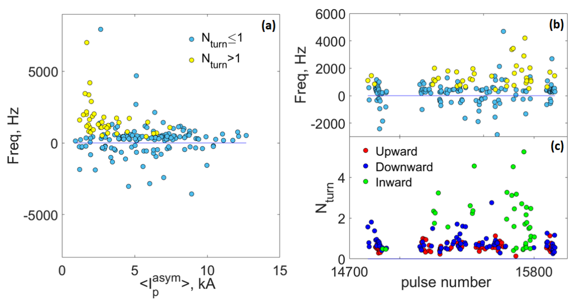

Figure 7: *(a) The rotational frequency of plasma current asymmetry versus the value of I_p^{asym} (b) Rotational frequency of plasma current asymmetry versus pulse number (c) Number of asymmetry rotations versus pulse number.*

short-circuit between limiter tiles near magnetic diagnostics (as expected according to ATEC model). COMPASS and JET plasma current toroidal asymmetries exhibit similar behavior: multirotational asymmetries only opposite to negative plasma current; rotational frequency decreases with the asymmetry magnitude. Further study of current misinterpretation is required: direct measurements of current flows towards the wall during disruptions are planned.

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References

[1] J. Wesson,, *Cambridge University Press, Cambridge*, (1987)
[2] K. Ikeda et al., *Nucl. Fusion*, **47** **(6)** (2007)
[3] S.N. Gerasimov et al., *37th EPS Conference on Plasma Physics*, (2010)
[4] S.N. Gerasimov et al., *Nucl. Fusion*, **55**, (2015)
[5] Roccella et al. *Nucl. Fusion*, **56**, (2016)
[6] S.N. Gerasimov et al., *ITPA MHD*, (2017)
[7] J.C. Wesley et al., *ITR/P1-26*