Contribution ID: **26** Type: **Contributed Oral**

Parametric study of Alfvénic instabilities driven by runaway electrons during the current quench in DIII-D

Tuesday, 19 July 2022 15:50 (25 minutes)

We report comprehensive investigation of Alfvénic instabilities driven by runaway electrons (REs) during the current quench in the DIII-D tokamak. These instabilities are observed as toroidal magnetic field fluctuations in the frequency range of 0.1–3 MHz and correlate with increased RE loss from the plasma which candidates them to be responsible for non-sustained RE beams and motivates a study to use such instabilities as an alternative or complimentary mean to massive impurity injection to avoid or mitigate RE beams in ITER.

It is found that decreasing the toroidal magnetic field (B_T) leads to instabilities shifting to lower frequencies, as expected for Alfvénic instabilities. As B_T decreases, the RE population becomes more energetic, the power of RE-driven instabilities increases, and no RE beam is observed when the maximum energy of REs exceeds 15 MeV (or when B_T is below 1.8 T). This may be caused by worsening conversion of plasma to RE current as B_T decreases and may explain the common empirical observation of high B_T favorable for sustained RE beams. Theoretically, decreasing B_T can decrease the on-axis current density (through $j_0 = 2B/_0qR$) which leads to lower post-thermal electric field and weaker primary RE generation. As a result, small RE population needs to be accelerated to higher energy in order to replace the decaying plasma current, and this more energetic RE population would increase the drive of instabilities.

Analysis of plasma disruptions at different plasma core temperature (T_e) shows that the RE population is much less energetic (with maximum energy of only 3 MeV) when T_e reaches about 8 keV, and no RE-driven instabilities are observed in this case. Since reactor-relevant high T_e increases the current conversion, this supports the results of the B_T experiment.

Besides the B_T and T_e experiments performed using Ar impurity injection, disruptions caused by massive gas injection (MGI) of Ne or D_2 were also studied. Both Ne and D_2 MGI result in no RE beam. Ne MGI leads to highly energetic RE population (with maximum RE energy exceeding 13 MeV even for a very substantial injection of 780 Torr·L) and one of the most clear Alfvénic instabilities. On the other side, no signs of REs nor Alfvénic instabilities are observed after D_2 MGI, which can be explained by slow plasma cooling (1.5 ms vs 0.5 ms for Ar MGI).

Measurements of the polarization of Alfvénic instabilities ($\delta B_T/\delta B_P$) indicates that it is of predominantly toroidal (compressional) nature, consistent with estimates and modeling suggesting excitation of Compressional Alfvén Eigenmodes. The toroidal mode number of these instabilities is found to be from −1 to +2, partially supporting the results of modeling presently not predicting n=0 mode.

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Session Classification: Disruption Consequences

Track Classification: Consequences