38th EPS Conference on Plasma Physcis P1.107

Generation and termination of runaway currents in KSTAR

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Abstract: Runaway currents following disruptions have an important effect on the first wall for the next generation tokamak. The behaviors of disruptions and runaway currents have been investigated in the KSTAR tokamak. A study of runaway current parameters has shown that the conversion efficiency of pre-disruptive plasma currents into runaway current is over 80% even at low toroidal magnetic field (B_T=1.3T) in KSTAR.

1. Introduction

The potentially damaging consequence of large runaway currents generated by disruptions is a key issue for next generation tokamak. The interaction of runaway electron (RE) beams with plasma facing components (PFCs) resulted in large heat loads, melting of the vacuum chamber. During the current decay phase of a disruption, runaway electrons can be generated in present day devices with energies of some 10's of MeV [1,2]. Eventually, this beam is lost to the first wall and can lead to severe damage. Due to amplification gain (*e*50) for ITER so large that any seed runaway electrons will result in up to 10 MA runaway current. Such current will inevitably cause severe damage to the device if it is locally deposited onto the PFCs. In order to elaborate on efficient methods of minimizing the deleterious effects of REs on PFCs, a good understanding of the mechanisms responsible for RE generation and confinement is required both from a theoretical and an experimental point of view.

KSTAR can provide an important disruption database for ITER due to its similar TF and PF magnetic coils. Extensive analysis of disruptions in KSTAR would help advance the understanding of trends of disruption-generated runaway electrons.

2. Experimental setup

The Korea Superconducting Tokamak Advanced Research (KSTAR) system is a

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full superconducting, medium-sized tokamak device. The KSTAR tokamak machine parameters include a major radius of R = 1.8 m, minor radius of a = 0.5 m, and the main operation goal parameters are plasma current I_P = 2.0 MA, B_T = 3.5 T, and pulse length t = 300 s. The KSTAR has 16 superconducting toroidal field (TF) coils and seven pairs of superconducting poloidal field (PF) coils, a vacuum vessel with thermal shields, and a cryostat. The superconducting magnet material of all the TF, PF coils 1–5 are Nb_3Sn while the PF 6 and PF 7 coils are NbTi. These are the same magnet materials as in the ITER coils. Therefore the TF and PF magnet coils could simulate the ITER magnet systems and many parts of the startup and the operation scenarios have relevance to ITER. KSTAR was dedicated in September 2007 and the first plasma was achieved successfully in June 2008. The first H-mode was achieved in 2010. The electron temperature was measured by an ECE radiometer which covers the frequency range of 110–196 GHz with 1 GHz steps.

3. Experimental results

The experiments described here were typically performed in deuterium discharges with a limiter configuration. Typical experimental parameters were toroidal magnetic field B_T=1.4-3.0T, toroidal plasma current Ip=200-600 kA, central electron temperature T_{e0}~ 1.5 keV, and line integrated electron density n_{e0}=(1-3) $\times 10^{19}$ m^{-3}.

Natural disruptions in KSTAR provided extensive data on runaway current generation at different toroidal magnetic fields and at different plasma currents. Plasma current decay times in KSTAR disruptions without runaway current are concentrated in a range between 5 and 20 ms over a wide variation of pre-disruption plasma currents and magnetic field strengths. The disruptions with runaway currents have been collected since the beginning of KSTAR operations. Different kinds of runaway currents have been observed in KSTAR. Disruptions with long live runaway currents have been observed. In Fig.1, discharge No. 2179 shows a disruption with a runaway current which decay slowly. The toroidal magnetic field is 2T and the plasma current is 240kA. The runaway current persisted about 650ms. Most of runaway currents formed current plateaus. Discharge No. 3305 in Fig.1 shows a disruption with runaway current plateau. The toroidal magnetic field is 2T also. The

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runaway current persisted about 1.2s. The runaway current plateau is about 156kA, which corresponds to 65% pre-disruption plasma current. The final quench of runaway current at 2.9s is due to the lost of plasma displacement, then the plasma was dumped to the first wall suddenly.

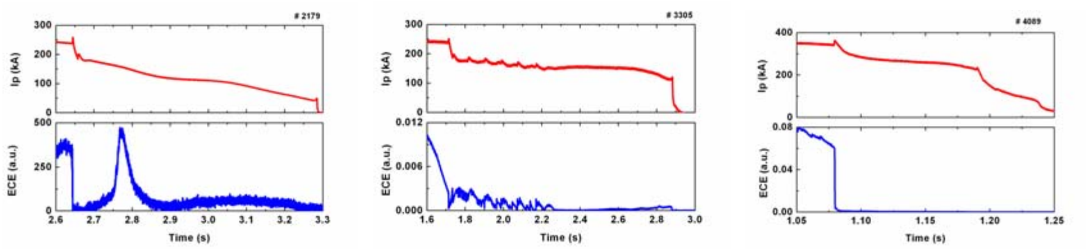

Fig. 1 Disruptions with runaway currents in KSTAR. (a) and (b) are disruptions at B_T=2T. In case (a), the runaway current decay slowly; in case (b), the runaway current formed a runaway current plateau. (c) is a disruption at B_T=1.3T. The runaway current was lost slowly due to the lost of displacement control after 1.18s.

In many experiments they found that the runaway current during disruptions depended on the magnetic field strength. Both experimental observations and theoretical predictions show that there is a magnetic field threshold for runaway electron generation in tokamak disruptions [1,3]. While runaway currents have been observed in a few disruptions at B_T=1.3 T in KSTAR. It has a different story compared to disruptions at low magnetic field from other machines. Discharge No. 4089 is a typical disruption with runaway current at B_T=1.3 T as shown in Fig.1. The plasma current is about 350kA. The runaway current plateau is about 260kA before 1.18s, which corresponds to 74% pre-disruption plasma current. The runaway current was lost slowly due to the lost of displacement control at 1.18s. The fraction of runaway current is even higher than the predicted runaway fraction (70%) in ITER. It was expected that whistler wave instability (WWI) excited by the runaway electrons will prevent the formation of runaway current during major disruptions at low magnetic field [3]. The growth rates of the most unstable whistler waves are inversely proportional to the magnetic field strength, and the WWI causes a rapid pitch-angle scattering of the runaways which may stop or reduce the runaway avalanche process.

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The generation of high fraction runaway current at 1.3T can not be explained by this theory. It will be our future study.

The fraction of conversion of thermal current to runaway current in all nature disruptions with runaway currents is shwon in Fig. 2. The conversion efficiency is almost independent of B_T. The disruptions without runaway currents at different magnetic fields are collected as shown in Fig.3. It is found that most of the disruptions at low magnetic field didn't generate runaway current.

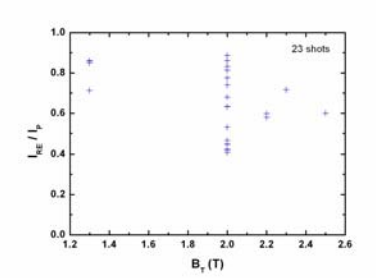

Fig.2 Fraction of runaway currents at different magnetic field.

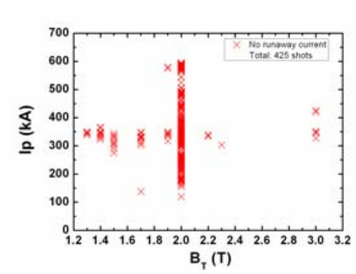

Fig.3 Collected disruptions without runaway current at different plasma currents and at different magnetic fields in KSTAR.

4. Conclusions

KSTAR can provide an important disruption database for ITER. The region that leads to runaway generation in disruptions has been investigated in KSTAR. The conversion efficiency of runaway currents during disruptions at different plasma parameters has been established. The disruption generated runaway currents can reach up to 80% of the pre-disruptive currents even at low magnetic field. It can not be explained by the WWI theory.

Acknowledgements: It is a pleasure to acknowledge the assistance of KSTAR group. This work was partially supported by the National Natural Science Foundation (No. 11005090) and National Magnetic Confinement Fusion Science Program (No. 2009GB104003).

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