S11-2

Development on Disruption Research with the Goal of DEMO Reactor Control
Status and Issues of Disruption Study
原型炉制御に向けたディスラプション研究の展開
ディスラプション研究の現状と課題

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Disruption control in tokamaks is one of the most important issues in the present and future devices because disruption has a large influence on the tokamak device through large heat loads and electromagnetic forces. In addition, runaway electrons generated during the disruption need to be suppressed because they damage the plasma-facing components through their high energy. In this paper, present status and issues on disruption study are briefly introduced by referring to recent topics discussed at the MHD, Disruptions & Control Topical Group of the International Tokamak Plasma Activity.

1. Introduction

Disruptions in tokamaks release a large amount of plasma energy and magnetic energy in a short time. Heat load and electromagnetic force caused by the disruption can have a serious influence on the plasma-facing components and tokamak device structure. In addition, runaway electrons can damage the plasma-facing components. For this reason, control of disruption is an important issue in ITER and DEMO.

Disruption study has a long history, and its results toward ITER are reviewed in ITER Physics Basis [1, 2]. Even with continuous efforts and significant progress, disruption is still one of the most important research topics in ITER and also in DEMO. In this paper, recent topics especially toward ITER are briefly reported; they would also be a good reference to disruption study for DEMO. The topics presented in this paper are mainly the ones discussed in the MHD, Disruptions & Control Topical Group (TG) of the International Tokamak Plasma Activity (ITPA), which operates under the auspices of ITER.

2. Disruption Research Activity toward ITER

Typical temporal evolution of disruption is schematically depicted in Fig. 1. When plasma collapse occurs due to MHD instabilities, significant degradation of the stored energy, which is called thermal quench (TQ), occurs. Then, a degradation of the plasma current, which is called current quench (CQ), occurs. It is considered in ITER that the CQ time should be in the range of 50-150 ms, because too short CQ time causes large electromagnetic force while halo current becomes a problem for too long CQ time. During the CQ phase, runaway electrons are generated.

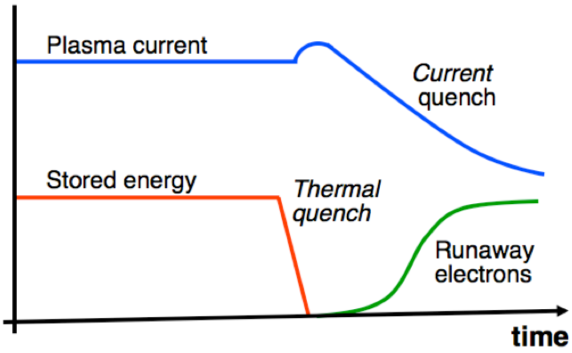

Fig. 1. Time sequence of disruption.

The ITPA MHD TG, which consists of 42 members from the ITER parties and the ITER Organization, discusses issues on MHD stability, such as sawtooth oscillations, neoclassical tearing modes and resistive wall modes. Issues on plasma control and error field are also discussed. Among them, disruption is the most important issues because a wide variety of complicated events occur in a short time as seen in Fig. 1. Multi-machine experiments and analyses on disruption are in progress. Typical ongoing research topics are as follows:

- Disruption mitigation by massive gas injection (MGI)
- Disruption database development
- Runaway electron generation, confinement and loss
- Disruption prediction
- Radiation asymmetry during MGI
- Halo current modeling

In these topics, asymmetry in the toroidal and poloidal directions, i.e. 3D disruption physics, is also an important research topic.

3. Selected Recent Topics on Disruption

3.1 Radiation during thermal quench

During the thermal quench, part of the plasma energy and magnetic energy is released as radiation. It is widely observed that the radiation is non-uniform both in the poloidal and toroidal directions. Since such non-uniformity can cause local heat spots exceeding the melting limit of the plasma-facing components, mitigation of the non-uniformity is an important issue.

The effectiveness of massive gas injection from several locations was investigated in several devices. In Alcator C-Mod, effects of the delay time of MGI from two gas injection valves located ~180º apart in the toroidal direction on radiation asymmetry were investigated [3]. The asymmetry was found to be reduced with decreasing delay in the pre-TQ phase. On the other hand, the asymmetry became unclear in the TQ phase. This suggests other effects such as MHD instabilities affect the asymmetry.

Radiation asymmetry was also investigated using a 3D code NIMROD including MGI process [4]. It was found that radiation asymmetry appears even for toroidally symmetric gas injection due to the existence of an m/n=1/1 mode (m and n are the poloidal and toroidal mode numbers, respectively). In addition, it was found that for gas injection from a localized location, the asymmetry is affected by the relation between the phase of the 1/1 mode and the gas injection location. Comparison with DIII-D experiments indicated that although such 1/1 mode structure was observed in radiation asymmetry, its magnitude was much smaller than expected [5].

In JET, the material of the plasma-facing components was modified to match those in ITER (called ITER-like wall, ILW). It was found that while the radiation fraction is 50-100% of the total energy for carbon tile cases, it is < 50% and also down to 10% for ILW cases [6]. This indicates that disruption mitigation is mandatory for ILW.

3.2 Halo current during current quench

When a disruption occurs and a vertical displacement event follows, a halo region is formed outside the last closed flux surface. Since an electrically closed path is formed through the halo region, plasma-facing components, divertor and vacuum vessel, large electromagnetic forces arise in these regions. Halo current distribution measured at different toroidal and poloidal locations indicated that there is significant non-uniformity. In addition, rotation of the asymmetric structure, which can affect the tokamak device through the natural period of the structure, was also observed [7]. Although the temperature profile at the halo region affects the decay of the plasma current, it is difficult to measure it in experiments. To investigate the temperature profile at the halo region, halo currents measured in several poloidal locations and those from DINA code calculations were compared. It was shown that by adjusting the temperature and its profile at the halo region, measured and calculated values agree well each other, in addition to the agreement of the plasma current evolution [8].

3.3 Runaway electrons

During the CQ phase, runaway electrons (REs) appear and grow. Since the REs can damage the first wall because of their high energy, it is necessary to establish how to mitigate REs. Several methods are proposed to mitigate and/or control REs. One is to inject massive materials like gas and pellets to reach the critical density at which REs decay through collisions. Experiments on several devices such as ASDEX-U and JET indicated that at present reachable electron density is far below the critical density. Another method is to control the runaway beams until the plasma current becomes low enough. Experiments on some normal-conducting devices demonstrated that RE beam can be controlled. DINA code simulations at ITER parameters indicated that under some conditions, e.g. disruption detection ~1 s before TQ and plasma position control, RE beams can be controlled until the plasma current including RE component decreases to ~2 MA [9]. Furthermore, the electric field at which REs are generated was investigated under the ITPA Joint Experiment [10]. It was shown that the electric field strength at which REs are generated is larger (3-5 times or more) than that predicted by relativistic collisional theory, suggesting the existence of other RE loss mechanisms.

References

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