RADIATION POWER LOSS STUDY DURING GAS PUFF INDUCED DISRUPTIONS IN ADITYA-U TOKAMAK

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Abstract

Understanding the density limit in a tokamak is very crucial for projecting the fusion grade tokamak machine. An important role in the disruptions for density limit is played by magneto-hydrodynamic (MHD) instabilities associated with the steepening of the current density profile due to the current channel contraction. This shrinkage in the current channel due to increasing densities is related to the plasma edge cooling induced by influx of particles. Thus the disruption associated with density limit not only depends on the magneto-hydrodynamic (MHD) physics, but also seems to involve transport and atomic processes as well. The gas puff experiments are carried out in a tokamak to understand the physics of plasma disruptions. We report here the study of radiation power loss in disruptive discharges. In Aditya tokamak, multiple pulses of hydrogen gas were injected during the current flattop in the plasma discharge. The gas puff lead to an increase of 20-80 % in central plasma density and many fold increase in the radiation power loss from the plasma edge [1]. The nature and distribution of radiation power loss was distinguishable in disruptive discharges and those discharges that had improved confinement [2], some of which were due to the edge cooling induced fluctuation suppression [3]. Similar experiments are carried out in Aditya-U tokamak with various gases, in which along with further establishment of the results obtained in Aditya with thorough data analysis, many interesting outcomes observed during the experiments in Aditya-U will be reported in this presentation.

1. INTRODUCTION

Tokamak disruptions are unfavorable events that result in the loss of the stored plasma energy and quenching of the plasma current over a very short period of time, thus generating huge forces on the vacuum vessel and subjecting the plasma facing components to enormous heat loads. These events are inevitable in plasma operation and the loss of confinement resulting into a disruption is attributed to many reasons including the operation limits in current and density, enhanced radiation losses, MHD instabilities and loss of plasma equilibrium. In this paper, we present the studies of radiation power loss and its distribution in gas puff induced disruptive and non-disruptive discharges.

Several features of disruptive discharges have been studied and earlier reported from the Aditya tokamak. The density limit disruptions were studied [1] and it was reported that the disruptions were initiated by the non-linear growth of large MHD modes due to the radiation cooling of the plasma edge. Also, it was reported that the major radiation power loss was during the current quench phase. Another study on the disruptions in Aditya reported the statistical study of the spontaneous disruptions [2] and the current quench time was found to be inversely proportional to the edge safety factor. The island width for both m=2 and m=3 modes was found to increase with the increase in the edge safety factor and also it was found to move towards the core, thus resulting in faster cross field transport and lower current quench time.

The hydrogen gas puff, which is frequently puffed in Aditya tokamak to increase the plasma density, has also been observed to result in the edge fluctuation suppression associated with edge cooling due to radiation [3]. The experimental measurements from Langmuir probe and bolometer diagnostics showed decrease in the edge density gradient, flattening of the floating potential and increase in the edge radiation. The effects were accompanied by significant reduction in the particle transport and enhancement of the particle confinement time.

The Radiative Improved (RI) mode was observed in Aditya tokamak on the puffing of neon gas during the current flattop. The neon gas puff resulted in an increase in the core plasma density and temperature along with increase in
the radiation power loss. The improved confinement was reflected in up-to two fold increase in the confinement time in R1 mode.

Similar experiments are carried out in Aditya-U tokamak with various gases, and we report here the outcomes of the experiments along with further establishment of the results obtained in Aditya.

2. EXPERIMENTAL MEASUREMENTS

The experiments were carried out in the Aditya tokamak and in the upgraded Aditya-U tokamak. Aditya is a medium sized air core machine of major radius 0.75 m and minor radius of 0.25 m and the toroidal magnetic field of around 0.75-1.26T. Plasma discharges of current 100-160 kA, chord averaged central electron density of 1.5 - 3 x 10^{19} m^{-3} and central electron temperature of 300 eV to 700 eV are routinely obtained on the machine with hydrogen as the working gas. For the study of disruptions, gas puff of hydrogen and neon is carried out using a piezo-electric valve (500 SCCM at 100V), which is mounted on the bottom port and is located 10 cm radially and 90° toroidally away from the limiter.

The upgrade of Aditya tokamak was carried out and the tokamak Aditya-U is made operational. The Aditya-U [4] is divertor machine and is aimed at producing plasmas with low loop voltage with strong pre-ionization and good plasma control system. It is also planned to carry out various experiments including the radio frequency heating experiments, current drive and disruption and runaway mitigation experiments. In this paper the measurements are presented from the circular plasmas produced in the Aditya-U tokamak.

The main diagnostics used in this study include the Rogowskii coils and loops for plasma current and loop voltage measurement and a set of 16 magnetic probes for plasma position measurement. The plasma internal energy is measured using diamagnetic loop [Sameer], and the central electron temperature is measured using soft x-ray system. An eight channel microwave interferometer is used for the electron density profile measurement. Hα and impurity line radiation is measured using visible spectrometer and photomultiplier tubes with wavelength filters.

The radiation power loss and its distribution are measured by AXUV detectors that are responsive to radiation from visible up to the soft x-rays. A single channel AXUV-100G detector that has a 2-pi view is installed on the radial port and gives the total power loss from the plasma. And for the measurement of the emission distribution, two linear arrays (AXUV-20ELG) are mounted on radial and top ports respectively. Both the arrays are mounted inside pin-hole cameras and provide a spatial resolution of 2-3 cm at the mid-plane (Fig. 1). The total radiated power is also determined from the array measurements by integrating along the radial and toroidal directions. The radial array is equipped with a manual shutter for detector protection during GDC. The arrays are frequently replaced to minimize the effect low energy radiation induced responsivity loss on the measurements. In order to further minimize this effect, new bolometer cameras were optimized before installing in the Aditya upgrade tokamak including the reduction in the pin-hole sizes. The electronics for the AXUV detectors is made in-house. An 8-layered PCB with high component density is designed to accommodate the amplification for all channels in a small housing. Each channel is equipped with a very high gain trans-impedance amplifier followed by a programmable gain amplifier and a fully differential driver. Also, the analog signal bandwidth is controlled using a programmable SC filter. The signal is acquired using the PXI based data acquisition system.

![FIG. 1 Line of sight of the radial array and the 2-pi detector](image)
3. RESULTS AND DISCUSSION

The gas puff experiments are performed in the Aditya-U tokamak to enhance the plasma density as well as to study the disruption behavior. The disruption exhibits interesting phenomenon in terms of the triggering event and evolution of the plasma parameters afterwards.

Figure 2 shows the evolution of plasma parameters in a gas puff induced disruption in Aditya-U Tokamak in which the current was around 100 kA and the plasma disrupted at \( t = 80 \) msec. Multiple gas puffs of width 2 msec were injected in the plasma at \( t = 50 \) msec (Fig. 3a). Along with the gas puff, a pulse of supersonic molecular beam (SMBI) was injected at \( t = 42 \) msec. The radiation power loss was well below the input power throughout the discharge. Hence radiation losses could not be accounted for triggering the disruption. Also, the plasma density was well below the density limit in this discharge (not plotted). The onset of the disruption is likely to be the growth of the large MHD mode as seen in the poloidal magnetic field derivative signal which is well correlated with the decrease in the SXR signal. Post disruption, the radiation power loss becomes nearly four times of its value before the onset of the disruption. It is observed that the power loss was more in the current quench phase as compared to the thermal quench. The other parameters from the same discharge are shown in figure 3. As soon as the disruption erupts, the plasma starts moving towards inboard side. The soft x-ray signal drops to zero in around 2-3 msec. The confinement degradation is further reflected in the decrease in the internal energy of the plasma.

**FIG. 2.** A typical Aditya Upgrade disruptive discharge (shot 31709). The signals shown are: (a) Plasma current, (b) Loop voltage and SMBI and gas Puff (c) Radiation power loss, (d) Input ohmic power, (e) time derivative of the magnetic field and, (f) Soft X-ray signal.
Neon gas is puffed in the tokamak edge as it increases the radiation from the plasma edge and hence assists in reducing the heat load on the plasma facing components. This also leads to the establishment of a radiative improved mode in the plasma, which is characterized by increased density and temperature at plasma core. The evolution of a discharge in a neon gas puff induced disruption is shown in figure 4.

FIG. 3. Some other parameters of the Aditya-U discharge 31709. The signals shown are: (a) Chord averaged density, (b) Plasma horizontal position, (c) Internal energy and (d) Radiation power loss.

FIG. 4. Neon gas puff induced disruption: Aditya-U discharge 31764. The signals shown are: Chord averaged density, Electron temperature, soft x-ray signal, Radiated and input power, Stored energy and current and loop voltage.
The neon gas puff is preceded by a pulse of hydrogen at $t=40$ msec. The gas puff leads to an increase in the density. Shortly after the neon gas puff, there is an increase in the radiation power loss at $t=60$ msec. The radiation loss almost equals the input ohmic power. This leads to confinement loss of the plasma. The radiation distribution from the radial array shows the increase in radiation from $t=52$ msec. The increase is more in the channels that view the plasma from $r=-80$ cm to $r=130$ cm.

![Graph](image)

**FIG. 5.** Bolometer array signals in neon gas puff induced disruption. Detector D5 looks at the edge below the mid-plane whereas D17 views the plasma edge above mid-plane.

CONCLUDING REMARKS

The radiation power loss and its distribution were studied in hydrogen gas puff and neon gas puff discharges. In the hydrogen gas puff discharges, the plasma disruptions were triggered by the MHD perturbations. The radiation power loss remained less compared to the input power. However, in case of neon gas puff induced disruptions, the radiation power loss was comparable to the input power and could have triggered the disruption.

REFERENCES