IMPROVED CONFINEMENT INDUCED BY TANGENTIAL CT INJECTION IN STOR-M

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Abstract

H-mode like discharges have been induced by tangential compact torus (CT) injection into the STOR-M tokamak. The improved confinement phase is characterized by an increase in the electron density, significant reduction in the H_α radiation level, steepening of the edge density profile, suppression of $m = 2$ Mirnov oscillations, and suppression of the floating potential fluctuations. These features are similar to those associated with the H-modes induced with edge turbulent heating or by electrode/limiter biasing in STOR-M. In contrast to the edge turbulent heating induced H-mode in STOR-M, the floating potential at the plasma edge and SOL increases during the CT injection induced improved confinement phase. Interaction between CT and edge tokamak plasma may be responsible for triggering the H-mode.

1. INTRODUCTION

Compact Torus (CT) injection as an emerging technology to centrally fuel a tokamak reactor was originally proposed by Perkins and Parks *et al.* [1]. Present fuelling technology, e.g., pellet injection, may be able to fuel an ITER like tokamak beyond the separatrix, but is unlikely to directly fuel the core region due to the maximum pellet velocity achievable. On the other hand, central fuelling of a large tokamak reactor with CT injection may have many advantages including high fuel burn-up rate, low tritium recycling and the potential to tailor the density profile for a high bootstrap current fraction. Early CT injection experiments carried out on the ENCORE tokamak resulted in an increase in current and a sharp density increase followed by disruption [2]. The non-disruptive CT injection experiments carried out on TdeV with CTF demonstrated central penetration with negligible impurity injection and showed some signatures of improved confinement of the tokamak plasma [3]. In both experiments, CTs were injected at the normal injection angle. Some theoretical models suggest that tangential CT injection has longer CT-plasma interaction time and smaller disturbance on the tokamak magnetic field [4]. In addition, tangential CT injection may also transfer CT momentum to tokamak plasma to induce and sustain toroidal rotation which has beneficial effects on stabilizing locked mode and resistive wall mode.

There are several questions concerning the CT injection fuelling technology, including CT penetration, impurity content, disturbance of the tokamak magnetic field structure, and effects on tokamak plasma confinement. Previous experiments have provided some encouraging results [3]. However, more details still need to be studied. The University of Saskatchewan Compact Torus Injector (USCTI) was built to study the underlying physics of CT-tokamak interaction. One of the unique features of the injection experiments on STOR-M is the variable injection angles.

In this paper, we shall report the characteristics of the H-mode like discharges in the STOR-M tokamak triggered by tangential compact torus (CT) injection.

2. EXPERIMENTAL SETUP

The University of Saskatchewan Compact Torus Injector (USCTI) used in the experiments consisted of formation and acceleration sections in a coaxial configuration. The surfaces of the

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injector were coated with either tungsten or chromium to minimize the impurity content in the CT. Hydrogen gas was injected into the injector chamber through four fast electromagnetic valves evenly distributed azimuthally. Two identical capacitor banks of 20 μF were used for consecutive formation and acceleration discharges. The voltages on the formation and acceleration banks were 15 kV and 10 kV respectively. A He-Ne laser interferometer was used to measure the CT density and an array of magnetic probes along the axial direction of the injector was used to measure the velocity and length of the CT. The typical CT parameters at the exit of the injector were: 5 cm in radius (accelerator radius), 15 cm in length, $(1 \sim 4) \times 10^{15}$ cm^{-3} in density, and approximately 150 km/s in velocity. The CT particle inventory of less than 1 μg was approximately 50% of that in STOR-M. The CT injection direction made 27$^{\text{o}}$ with the tokamak normal at the injection location as shown in Fig. 1.

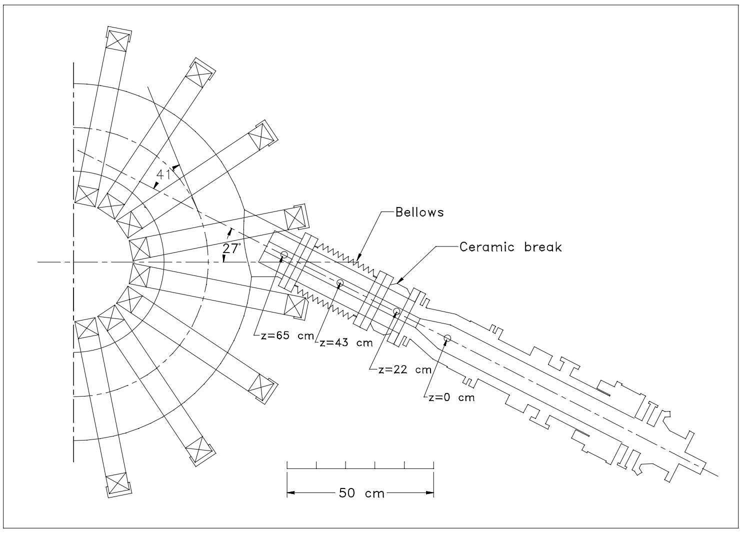

FIG. 1. Arrangement of CT injection into STOR-M.

The STOR-M tokamak was equipped with programmable gas puffing valves and position feed-back control system. The limiter was a combination of horizontal rail limiter at $r = 12$ cm and circular limiter at $r = 13$ cm near the mid-plane. This limiter configuration allowed a plasma horizontal displacement up to 1 cm without further scrapping-off. In the CT injection experiments, the tokamak plasma parameters were monitored with various diagnostic tools. A 4 mm microwave interferometer was used to measure the electron density averaged along the central vertical chord. A spectrometer aiming horizontally through the centre of the discharge was employed to monitor the H_α emission intensity. A rake probe array was installed to measure the electron density and floating potential at the plasma edge. A set of Mirnov coils outside of the chamber wall was used to monitor $m = 2$ and $m = 3$ MHD activities. The hydrogen plasma was heated ohmically without auxiliary heating. The nominal plasma parameters were: $R = 46$ cm, $a = 12$ cm, $B_t = 0.8$ T, $I_p = 20$ kA, and $\bar{n}_e = (0.5 - 2) \times 10^{13}$ cm^{-3}.

3. EXPERIMENTAL RESULTS

Following the preliminary CT injection experiments on STOR-M [5], USCTI was modified to achieve break-down with an 80% reduction in gas injection, which significantly reduced trailing gas. In addition, the tokamak toroidal magnetic field was increased from 0.7 T to 0.8 T to improve the tokamak discharge rigidity against the impact of CT injection. These measures facilitated disruption-free CT injection into STOR-M and allowed further study on CT injection induced H-mode like discharges in STOR-M.

Figure 2 shows the waveform of the tokamak discharge parameters: from top, plasma current, loop voltage, electron density, horizontal displacement, H_α radiation intensity, and $m = 2, 3$

MHD oscillations. Following the CT injection at $t = 15$ ms, the discharge current and loop voltage remain almost intact, indicating a constant Spitzer temperature. The electron density increases from 0.85×10^{13} to 1.8×10^{13} cm^{-3} and then remains at this high level until the end of the discharge. The global energy confinement time, without taking the CT power input into account, increases from 1 ms (prior to CT injection) to 2.5 ms maximum. The plasma position shifts outwards during the time interval between $t = 15$ ms and $t = 20$ ms, owing to the increase of the stored energy in the discharge column as the result of density increase. The H_α decreases abruptly following the CT injection by approximately 35% and returns to the nominal level at $t = 20$ ms, indicating an L-H transition and an H-L back transition respectively. The $m = 2$ MHD oscillation level decreases after the CT injection and starts to grow at $t = 18$ ms. The $m = 3$ MHD oscillation level experiences little change initially until $t = 18$ ms, when it starts to grow. Both $m = 2$ and $m = 3$ oscillations grow prior to H-L back transition and have a peak at $f = 25$ kHz in their power spectra. Figure 3 shows the significant reduction in the floating potential level at locations across the scrap-off-layer (SOL) and edge region following the CT injection. It has been noted that the following phenomena occur coincidently: (a) reduction in H_α radiation intensity, (b) increase in electron density, (c) suppression of floating potential, and (d) plasma outward displacement.

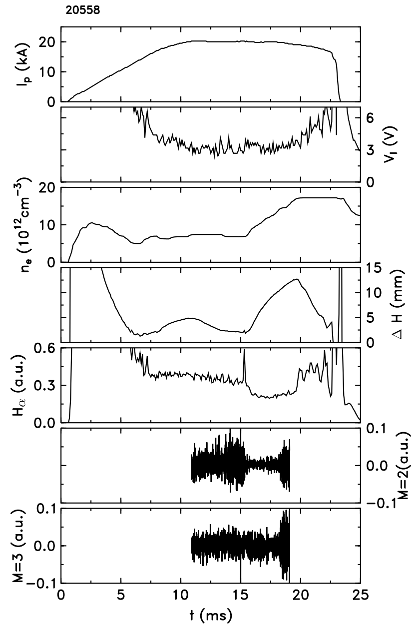

FIG 2. Tokamak plasma parameters.

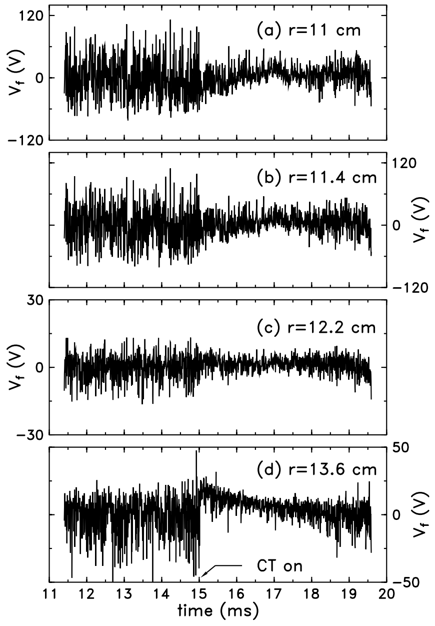

FIG 3. Floating potential fluctuations.

The electron density and floating potential profiles at the STOR-M edge region were studied using the rake probe array. Figure 4 shows the time evolution of the electron density profile. The density decreases 2 ms initially after the CT injection and then increases and steepens gradually in the rest of the improved confinement phase. After $t = 21$ ms, the density gradually returns to the profile before CT injection. Figure 5 shows the time evolution of the floating potential profile. Following CT injection, the floating potential increases and steepening of the profile occurs. This indicates that L-H transition was accompanied by an enhanced radial electric field. At a later time, $t = 21$ ms, an inward electric field emerges between $r = 10.9$ and $r = 11.3$ cm.

4. DISCUSSIONS AND SUMMARY

Theoretical models suggest that the full CT penetration condition is $\frac{1}{2}\rho_{\mathrm{CT}}V_{\mathrm{CT}}^2 > \frac{1}{2\mu_0}B_{\mathrm{t}}^2$, where ρ_{CT} is the CT mass density, V_{CT} the CT velocity, and B_{t} the tokamak toroidal magnetic field. Central CT penetration into STOR-M is not expected in this experiment. The energy deposition and magnetic field restructuring at the tokamak edge due to CT shallow injection may have favoured a synergy leading to the L-H transition. If deposition of the kinetic energy

(11 J) and magnetic energy (47 J) carried by the CT occurs in 5 ms, an average power of 12 kW (the instantaneous power peak may be much larger) is released to the discharge in addition to the 75 kW of ohmic heating power. The situation is similar to the H-mode induction through edge turbulent heating using a short current pulse in STOR-M [6].

In STOR-M, ohmic H-mode like discharges have been induced by edge turbulent heating, CT injection, and limiter/electrode biasing. In the biasing experiments, H-mode could be induced by either positive or negative bias. Unlike the H-mode induced by turbulent heating, where negative auto-biasing was observed, the H-mode induced by CT injection is accompanied by positive auto-biasing. It shows that the sudden change in the electric field (either actively applied or spontaneously formed), together with edge electron density profile steepening, is one of the important factors leading to reduction of turbulence induced transport.

In summary, the H-mode like discharges triggered by CT injection in STOR-M are accompanied by an increase in the electron density, significant reduction in the H_α radiation level, steepening of the edge density profile, suppression of the $m = 2$ Mirnov oscillations, and suppression of the floating potential fluctuations. These features are similar to those associated with the H-modes induced with edge turbulent heating or by electrode/limiter biasing in STOR-M. In contrast to the edge turbulent heating induced H-mode in STOR-M, the floating potential at the plasma edge and SOL increases during the CT injection induced improved confinement phase.

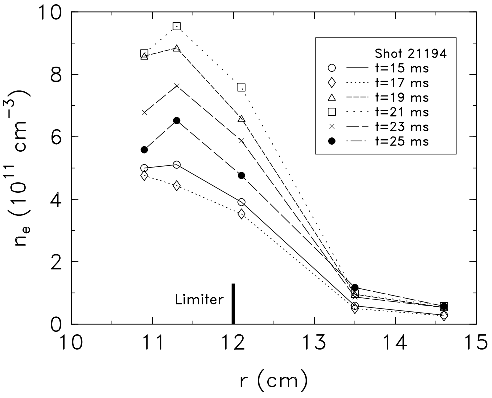

FIG 4. Edge density profile.

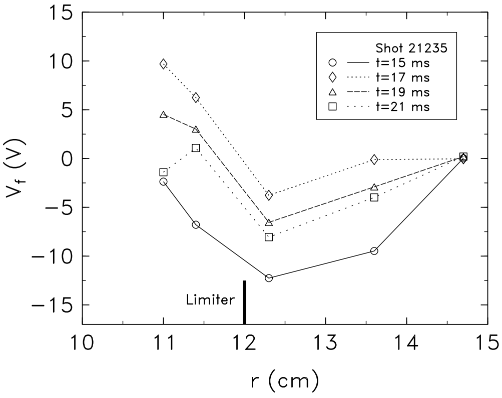

FIG 5. Floating potential profile.

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