ABSTRACT

A characterisation of the H mode in Tokamak de Varennes (TdeV), combining results obtained from spectroscopic measurements with observations of global plasma parameters is presented. Controlled L and H modes are obtained by applying an external biasing on the divertor plate and/or by varying the plasma triangularity using similar steady-state discharges with ECRH heating. The poloidal velocities are small with no significant variations with respect to the plate biasing, EC power and plasma triangularity. Toroidal rotation velocities show more consistent trends and have larger values in the H modes with respect to the L modes. No significant shear in the radial electric field is observed between the H and L modes. Differences in the electric field and in the ExB shear are observed for several discharges but they are not consistent overall. The energy confinement time decreases with the ELM severity and consequently with the neutral fluxes. The presence of a toroidal torque which affects the particle transport inside the plasma plays an important role in the TdeV H modes.

1. Introduction

In this paper we present results of H modes compared with L modes created in TdeV (divertor single null configuration tokamak). Two methods were used to achieve well controlled stationary H modes exhibiting type III ELMs in addition to auxiliary heating (ECRH and LH): varying the plasma lower triangularity and applying a biasing between the divertor plates and the vacuum chamber. H and L mode TdeV discharges with similar parameters were chosen: $B_T = 2$ T, $I_p = 160-220$ kA, $<n_e> = 2-5 \times 10^{19}$ m$^{-3}$, $R=0.83$ m, $a = 0.21$ m, with the $B \times \nabla B$ drift both towards (more favourable to H modes) and away from the X point but different plasma triangularities (0.1-0.24), biasing voltage (-310 to 250V) and deposited EC power (150-480 kW). The edge density was fixed during the discharge (slightly higher than the L-H density threshold in order to pass easily from an L to an H mode), leaving the central density free to vary. The machine walls were boronised, reducing the oxygen and carbon impurities. Spectroscopic measurements of the rotational velocities are presented and discussed together with more general results on the plasma parameters during the L and H modes. As the temporal resolution of our spectroscopic system is low (200 ms), these results characterize the steady-state H and L mode phases rather than the L-H transition, and are averaged over ELMs.

A typical H mode observed in TdeV is shown in Figure 1: a drop in the $D_a$ radiation with a presence of ELM activity, a rise in the total stored energy and energy confinement time, and a rise in the line-averaged electron density. The electron density (measured with a 9-channel submillimeter interferometer) and temperature radial profiles (measured with a 8-channel infrared Thomson scattering diagnostic) in H modes obtained by varying the triangularity and the divertor plate bias (not
shown here) readjust such that the local pressure remains approximately constant. Unfortunately the spatial resolution for both the interferometer and Thomson scattering diagnostics is too low to clearly see the presence of a pedestal inside the separatrix. The electron density profile around the separatrix measured by the reflectometer (33-75 GHz), is observed to be steeper in the H mode than in the L mode (see Figure 2). In TdeV, the normal direction of the plasma current, $I_p$, refers to the clockwise direction looking downwards ($B \times \nabla B$ drift away from the divertor). The central ion temperature, the total radiated power and $Z_{\text{eff}}$ were measured respectively with the charge-exchange analyser, bolometer system viewing the whole poloidal section of the hot plasma, and visible Bremsstrahlung radiation.

Two calibrated soft X-ray spectrometers viewed radially the central and half-radius plasma. Reference [1] provides more details of these diagnostics. The emissivities, the poloidal and toroidal velocities and the ion temperature profiles were measured simultaneously with a spectroscopic set-up observing the plasma both poloidally and tangentially using chords in the vertical plane (see Figure 3).

The line integrated signals deduced from the Doppler shifts and broadenings of BV (at 494.4 nm) and CIII (at 464.7 nm) emission lines were inverted using a matrix inversion method where the real flux lines were deduced from experimental coil currents and a (MHD) magnetohydrodynamic equilibrium code.

2. Results

Considering that the maximum emission of CIII and BV is localised in the region $r/a = 0.6-1.2$, only profiles within this range are available. In Figure 4 is shown the dependence of the rotation velocity of the applied bias for discharges with H and L modes. Averaged velocity values around $r/a = 0.85$ ($0.8 < r/a < 0.9$) and 1.0 ($0.95 < r/a < 1.05$) are considered for bottom and top poloidal and toroidal velocities. The biasing is applied between the upper divertor plate and the wall and one would expect to see a stronger effect in that region. The poloidal velocity is generally low with small differences between the values in the H and L modes. The error bars are high due to the low brightness in the poloidal view. The biasing does not seem to affect the poloidal velocities at both locations (inside and around the separatrix) whereas it clearly affects the toroidal velocities, more prominently inside the separatrix. This means that the biasing has an effect deeper inside the plasma even if it is applied in the SOL. There is a threshold in both top and bottom toroidal velocity when passing from L to H
mode (Δν ~4-6 km/s). The CIII poloidal velocity is also weak (see Figure 5). The toroidal velocities see an effect of the biasing, more prominent in the upper part, for both plasma currents. This observation is similar to the one observed for BV around r/a =1 but with larger velocities. The radial profile of the electric field (Er) was calculated with the momentum balance equation from the BV line, for the discharges with Ip at 160 kA and 220 kA respectively. The BV ion density profile was calculated using the transport code MIST. The \( v_0B_\theta \) and \( v_pB_\theta \) terms dominate over the pressure gradient term (the differences between the temperatures in H and L mode are only 15-20%).

Inside the separatrix (region where the difference in the electron density gradient between the L and H modes is observed), the contributions from the poloidal and toroidal velocities are comparable;

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**Fig. 4**

**Fig. 5**

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**Fig. 6**

**Fig. 7**

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differences in the profiles of the $E_r$ are observed between different biasing voltages (more prominent further inside the separatrix at $r/a<0.9$). Unfortunately, the error bars associated to $E_r$ are high due to the errors in the poloidal velocity. A similar behaviour in the $E_r$ calculated using CIII (not shown) for $r/a > 0.95$ was observed, confirming the absence of a strong shear in that region.

As can be seen from Figure 6 (a) there is a jump in the energy confinement time, ELM severity\(^4\) (b), ELM frequency (c), radiated power(d), SX radiation (e) and $Z_{\text{eff}}$ (f) when passing from negative to positive biasing. This behaviour is similar to that observed in the toroidal velocities inside the separatrix. H mode discharges obtained with different discharge scenarios are plotted in Figure 7. A general tendency in the energy confinement time to decrease with the ELM severity is seen for both 220 and 160 kA. A correlation between the ELM severity and the electric pressure and the edge electron density is observed only at 220kA, with no substantially change at 160 kA. Lower ELM severity is observed for higher edge electron density (which is the parameter used to control the L-H transition).

3. Discussions and conclusion

As a general observation, the poloidal velocities in TdeV remain relatively small during the steady-state phases of both H and L modes. The experimental uncertainties are high for this parameter but we conclude that there is no significant poloidal rotation in the H mode. Even if there is rotational shear during the L-H transition (which we cannot measure), the velocity returns to low values. The weak poloidal velocities might not be the crucial factor in the evolution of the TdeV H mode.

The ion temperature in the H mode is slightly higher than in the L mode but only by 10-20%. No important shear is observed in the electric field even if there are differences in the electric field itself and its shear between the H and L modes. The toroidal velocities are higher in the H mode than in the L mode. This behaviour has been seen consistently for the H modes obtained using different methods. The divertor bias and the plasma triangularity have a clear effect on the toroidal velocities which seem to be a key parameter in the H modes in TdeV. The energy confinement time decreases with the ELM severity and consequently with the neutral fluxes. The fact that the toroidal velocity has high values and depends on the majority of the plasma parameters in the H modes\(^5\), suggests that the presence of a toroidal torque which affects the particle transport inside the plasma may play the primary role in the TdeV H modes.

REFERENCES

1 The TdeV team, CCFM internal report, CCFM RI 450f, (1994).