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Experimental Study of the Ohmic Density Limit in HL-1M

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Abstract

Density limit investigations have been performed under a variety of discharge conditions on HL-1M, including hydrogen isotope, silicon wall coating and a variety of fuelling methods (gas puff, pellet and supersonic molecular beam (SMB) injection). Detailed analysis shows that the HL-1M density limit is a disruptive limit and it is related to first wall recirculating and fuelling methods. The destruction of balance between radiation and input power is the main reason for the density disruption.

Keywords:

Density limit, discharge condition, density disruption

1. Introduction

As the emphasis of the world's tokamak programmes moves towards reactor relevant regimes, the plasma behaviour at high density during the steady state becomes an increasingly important issue.

In exploring the operating regime of a tokamak, researchers have always found a limit in the maximum density that they could achieve. Attempts to raise the density beyond this limit result in a disruption of the discharge. The classical description of the scaling for the density limit is well known as the Murakami-Hugill limit [1], and a refined scaling, including the plasma elongation, has been proposed by Greenwald *et al.* [2]. The value of the density limit is found to vary from machine to machine [3-5]. In this paper, we present density behaviour in HL-1M tokamak, and systematically examine Ohmic and L mode density limit data during different operating conditions.

2. Experimental Set-Up and Diagnostics

HL-1M is a modification of the HL-1 tokamak [6]. The typical limiter configuration in HL-1M has a circular cross-section, with a major radius R and a minor radius of 1.02 m and 0.26 m, respectively. Two fully poloidal graphite limiters are separated by 180° from each other toroidal. The main working gas is hydrogen. The operational region of the discharges considered is as follows: plasma currents of Ip < 200 kA, a toroidal magnetic field Bt < 2.2 T, and pulse duration ≈1s for normal operations [7]. The line averaged electron density $\bar{n}_e$ for the central chord is measured by the six-channel HCN interferometer [8] and the density profile is calculated using the same interferometer data [9]. The minimum detectable fluctuation in $\bar{n}_e$ is about 1×10^{12} cm^{-3}. With a 14-channel bolometer array, the radiation power can be measured, and the time resolution is 1 ms. A thirty-six-channel PIN diode array is installed on HL-1M for the study of soft x-rays emission.

3. Density Limit

In 1994, HL-1 was modified to HL-1M by replacing the vacuum chamber. The plasma minor radius was increased from 0.2 m to 0.26 m. During the past years of operation, different wall processing materials (boronization, siliconization, lithium coating) have been exposed to the HL-1M, many fuelling techniques (gas puffing, pellet injection, supersonic molecular beam

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injection) have been used. Because of the good progress on HL-1M, the plasma operational regime is wider than that in HL-1. The Hugill parameter H = $\bar{n}_e Rq_a/B_t$ from 6.9×10^{19} $m^{-2}T^{-1}$ increases to 15×10^{19} $m^{-2}T^{-1}$.

Throughout this paper, the typical density limit shots is used, in which before the plasma collapse, the plasma position is not appreciably shifted. In these shots, the line averaged density keeps increase with the continuous gas feeding until a sudden break occurs, and the radiative loss suddenly increases non-linearly. During the phase of disruption, the MHD turbulence appears before the disruption and the oscillation frequency decreases to about one half. Meanwhile the amplitude of the oscillation becomes many times larger, but in the signs of SX, there is no lock mode occurred.

Deuterium and hydrogen ohmic discharges have been studied on HL-1M. Comparing hydrogen and deuterium as the discharge gas, the isotope effect is observed. The density limit in deuterium is somewhat higher than that in hydrogen, the Murakami parameter in deuterium plasma is 1.5 times larger than that in hydrogen plasma, and the isotope effect scaling is $\bar{n}_e \propto m^{1/3}$, where m is the mass of the deuterium or hydrogen.

In the HL-1M the influences of wall materials surrounding a plasma have been explored. The experiments started with no silicon film metallic walls facing the plasma surface. The maximum average density achievable is a linear function of the plasma current up to a maximum current (see Fig. 1). Metallic walls and limiters however pollute the plasma with metallic and carbon impurities and provide plasma with a high Z_{eff}. After coating the inner surface of the machine with a thin silicon film (siliconization), not only metallic impurities but also carbon and oxygen of the plasma were almost completely removed and a higher density was achieved over the whole current range. The result is shown in Fig. 2 in Hugill-diagram. After siliconization, the density limit was slightly shifted to higher values. Above observations prove that the impurities and recycling from first walls play an important role in achieving higher density limit. An improved conditioning of the vessel walls will lead to a higher density limit.

Fuelling tokamak plasmas in a more efficient way is very important to obtain higher density limit (see fig. 2). As a key device to produce a supersonic molecular beam , which is a more effective fueling method than the normal gas puffing, the Laval nozzle [10] was installed on HL-1M. With the hydrogen beam velocity about 260 m/s, the pulsed molecular beam is injected into the plasma. The maximum density $\bar{n}_e = 8 \times 10^{19}\,m^{-3}$ has been obtained (see Fig. 3) and it was about 80% Greenwald density limit (show in Fig. 4). As is seen in Fig. 3 during the density increase in the supersonic molecular beam injection phase (t = 50 ms, SMB was began injected into plasma), high edge plasma radiation on the high field side was observed, and then the MHD-instabilities lead to a plasma disruption.

If the density peak factor (V_n) is defined by $V_n = \bar{n}_e(r = 0)/\bar{n}_e(r = 0.57a)$, the global database from the operational region of HL-1M shows that V_n = 1.65–3.5 with SMB discharge and V_n = 1.4–2.78 with gas puff discharge. The high peak factor of density is benefit to obtain high density limit. This result is similar to the reports from JT-60U [5] and ASDEX [4].

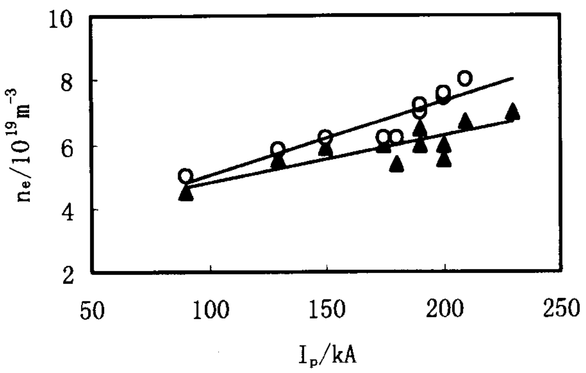

Fig. 1 Plot of n_e versus plasma current I_p for before (triangle) and after (circle) siliconization

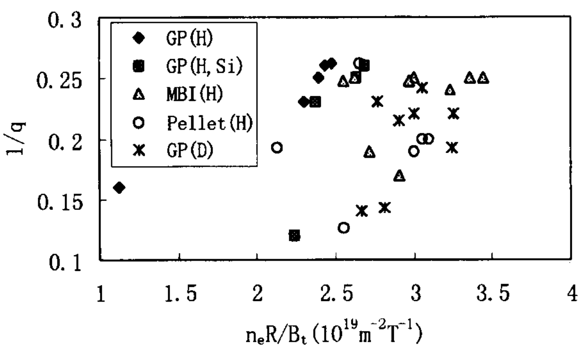

Fig. 2 Hugill plot of density limit results for the Ohmic discharges in the HL-1M (GP(H): gas puffing in hydrogen; GP(H,Si): gas puffing in hydrogen after siliconization; MBI(H): supersonic molecular beam injection in hydrogen; Pellet(H): hydrogen pellet injection; GP(D): gas puffing in deuterium).

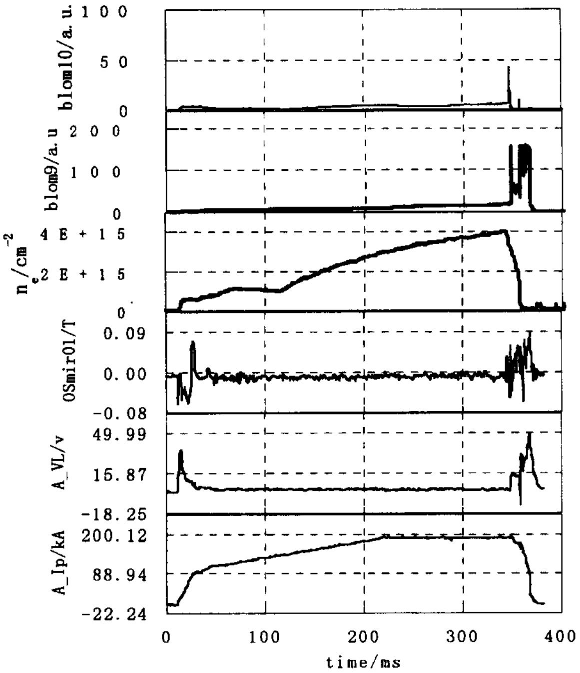

Fig. 3 The density limit discharge waveform of supersonic molecular beam injection. bolm9: edge bolometer signal on the high field side. bolm10: edge bolometer signal on the low field side. Osmir01: mirnov probe signal. n_e: line-density, A_Ip: plasma current, A_VL: plasma circulating voltage.

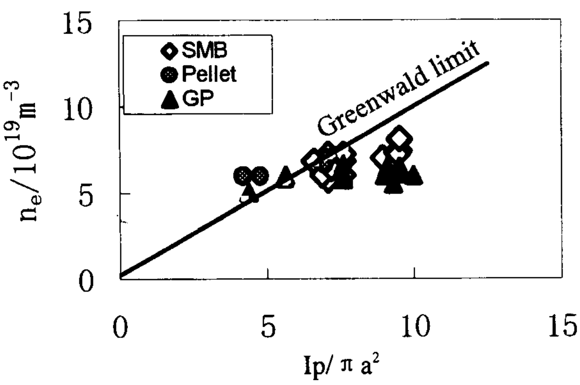

Fig. 4 Plot of density versus $Ip/\pi a^2$ for the HL-1M density limit discharge data. The real line is Greenwald limit. The diamond is SMB injection discharge.

4. Conclusions

This paper presents the L-mode density behavior in the HL-1M tokamak, and studies systematically the influence of varied discharge parameters at the ohmic plasma density limit. The sequence of processes leading to a density limit disruption was experimentally analyzed. Experimental results show that the density limit may be caused by an destruction of balance between input and radiated power, and the Murakami parameter is a good scaling parameter for the density limit in HL-1M discharge.

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