ENERGY CONFINEMENT IN OHMIC H-MODE IN TUMAN-3M

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Abstract

The spontaneous transition from Ohmically heated limiter discharges into the regime with improved confinement termed as "Ohmic H-mode" has been investigated in "TUMAN-3". The typical signatures of H-mode in tokamaks with powerful auxiliary heating have been observed: sharp drop of D_α radiation with simultaneous increase in the electron density and stored energy, suppression of the density fluctuations and establishing the steep gradient near the periphery. In 1994 new vacuum vessel had been installed in TUMAN-3 tokamak. The vessel has the same sizes as old one (R_0=0.55 m, a_l=0.24 m). New vessel was designed to reduce mechanical stresses in the walls during B_T ramp phase of a shot. Therefore modified device – TUMAN-3M is able to produce higher B_T and I_p, up to 2 T and 0.2 MA respectively. During first experimental run device was operated in Ohmic Regime. In these experiments the possibility to achieve Ohmic H-mode was studied. The study of the parametric dependencies of the energy confinement time in both OH and Ohmic H-mode was performed. In Ohmic H-mode strong dependencies of τ_E on plasma current and on input power and weak dependence on density were found. Energy confinement time in TUMAN-3/TUMAN-3M Ohmic H-mode has revealed good agreement with JET/DIII-D/ASDEX scaling for ELM-free H-mode, resulting in very long τ_E at the high plasma current discharges.

1. Introduction

H-mode was discovered in 1982 in the experiments with powerful heating by Neutral Beam Injection in ASDEX [1]. Since that time H-mode was found in a number of experiments with different auxiliary heating schemes. In a majority of the experiments L-H transition takes place in a divertor configuration but in some cases the H-mode was observed in the limiter bounded plasmas also. In ordinary Ohmic regime the transition into the improved confinement regime similar to H-mode was found in the TUMAN-3 tokamak in circular limiter configuration [2].

2. Energy confinement time parametric studies in TUMAN-3M device

TUMAN-3 is a small tokamak with circular cross section and metallic walls and limiters [3]. After modification including replacement of the vacuum vessel device was named TUMAN-3M. New vessel was designed to reduce mechanical stresses in the walls during B_T-ramp phase of a shot. Therefore modified device - TUMAN-3M is able to produce higher B_T and I_p up to 2 T and 0.2 MA respectively. Some machine and plasma parameters are listed in Table 1.

Energy confinement time parametric dependencies were studied using diamagnetic measurements of a stored energy. τ_E dependency on density for OH with two different values of plasma current are given on Fig. 1. The data show weak density dependence at given current and substantial increase in τ_E with I_p. Similar dependencies were found in the tokamak Alcator-CMOD. At lower densities experimental energy confinement time exceeds Neo-Alcator

Table 1. TUMAN-3/TUMAN-3M parameters.

	Range	Typical OH
R_0, m	0.44-0.64	0.53-0.55
a_l, m	0.11-0.24	0.22-0.24
B_T, T	0.34-1.2 (2.0)	0.40-0.8
I_p, MA	0.04-0.16 (0.2)	0.09-0.15
n_{av}, 10^{19} m^{-3}	0.4-5.2	1.0-2.5
T_{e0}, keV	0.3-0.8	0.5-0.6
T_{i0}, keV	0.09-0.17	0.12-0.15

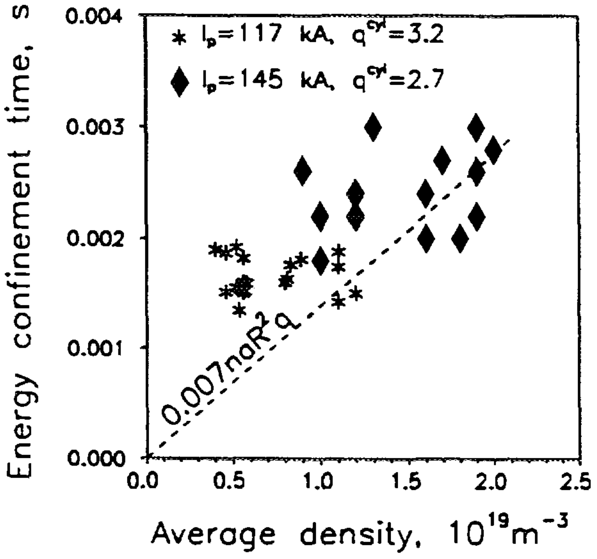

Fig. 1. Energy confinement time as function of density for OH regimes with I_p=117&145 kA.

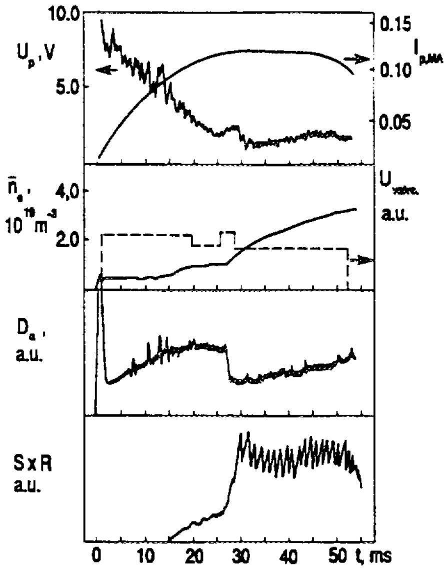

Fig. 2. Temporal evolution of some plasma parameters in 115 kA Ohmic H-mode.

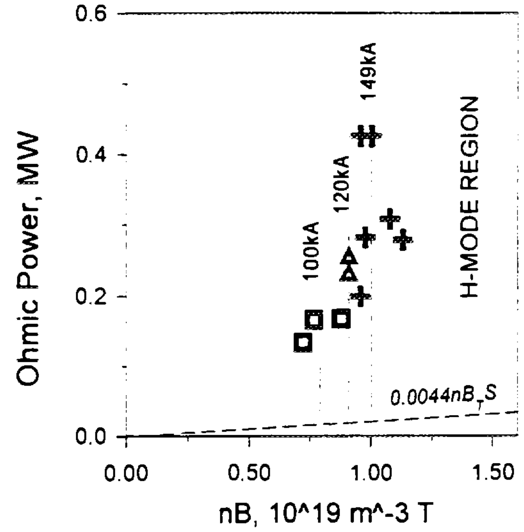

Fig. 3. H-mode operational region. Symbols show input power before transition into Ohmic H-mode.

predictions by a factor of two [4]. Low recycling may result in diminish of the atomic processes influence on confinement and corresponding changes in parametric dependencies.

Ohmic H-mode appears spontaneously or could be triggered by some increase in deuterium puffing rate, as in TUMAN-3M [2]. Typical waveforms of some plasma parameters in the 115 kA Ohmic H-mode are shown in Fig. 2. Transition starts at 27 ms. During this period D_α and U_p are decreased indicating gradual reduction of the particle flux in periphery and widening of the current density profile. The Ohmic H-mode is ELM-free and is

Table 2. Examples of the scalings describing energy confinement in Ohmic L- and H- modes.

Scaling, Expression ($1\bullet10^{19}$ m^{-3}, m, MA, MW, T, keV)	τ_E, ms
Neo-Alcator $7naR^2q^{cyl}$	1.9
Merezhkin-Mukhovatov $1.1na^{0.25}R^{2.75}qk^{0.}125A_i^{0.5}/<T_e>^{0.5}$	2.3
Goldston (L-mode) $37I_p^{0.85}P^{-0.5}R^{1.75}a^{-0.37}k^{0.5}(A_i/1.5)^{0.5}$	10.7
ITER89-P (L-mode) $48I_p^{0.85}R^{1.2}a^{0.3}k^{0.5}n^{0.1}B_T^{0.2}A_i^{0.5}P^{-0.5}F[f_s^{\alpha-s}f_q^{\alpha-q}]$	9.9
DIII-D/JET (H-mode) $110P^{-0.46}I_p^{1.03}R^{1.48}$	15.6

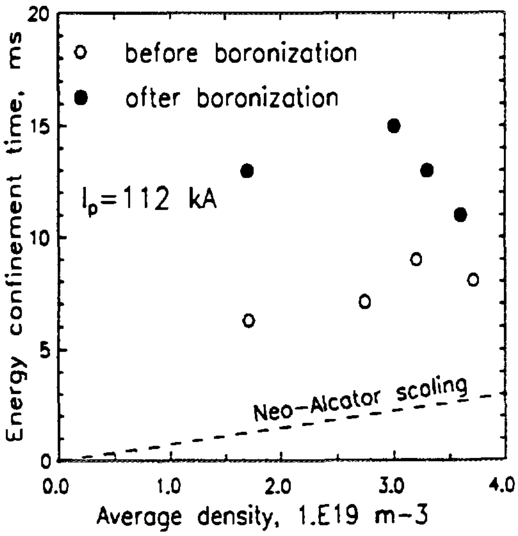

Fig. 4. Energy confinement time as a function of density for the regime with current 112 kA before and after boronization.

characterized by continuous density increase indicating improvement in particle confinement. After transition SXR emission from the plasma center increases due to electron temperature rise.

Fig. 3 presents H-mode operational region in the (P_{input}, nB_T) coordinates. Points show plasma parameters just before transition into the Ohmic H-mode. Discharges enter H-mode operational space from the low density margin (shown by vertical lines). It should be mentioned that all points lie substantially higher threshold power [5].

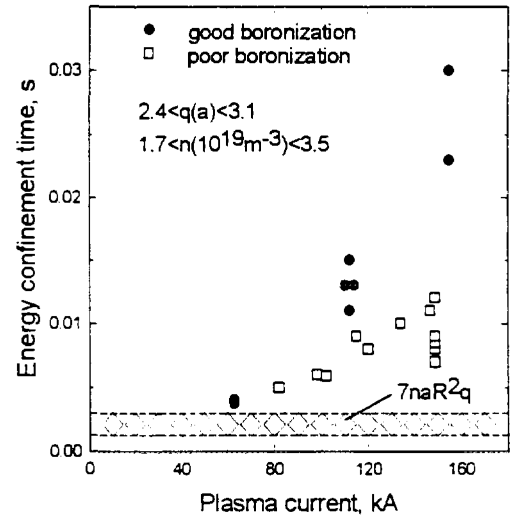

Fig. 5. Energy confinement time as a function of plasma current in TUMAN-3 and TUMAN-3M Ohmic H-mode.

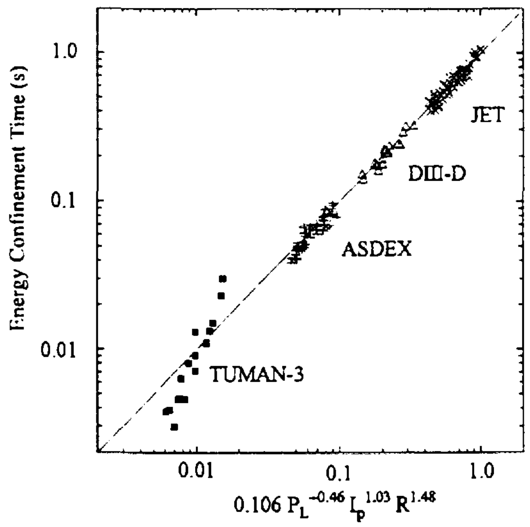

Fig. 6. Experimental energy confinement time in Ohmic H-mode as a function of JET/DIII-D H-mode scaling.

To describe an energy confinement in Ohmic, L- and H- modes of tokamak operation different expressions are usually used, see Table 2. Typical Ohmic scaling predicts linear dependencies of energy confinement time on average density and safety factor. Size dependence is cubic. Examples of this kind of scalings are “Neo-Alcator” [6] and “Merezhkin-Mukhovatov” [7]. Energy confinement in the auxiliary heated L-mode plasmas is characterized by rather different dependencies. τ_E appears to be proportional to plasma current and inversely proportional to square root of input power. Frequently cited expressions are “Goldston” [8], “ITER89-P” [9]. Parametric dependencies of τ_E in H-mode plasma are only slightly different from that ones in L-mode. Example of the expression for H-mode plasma is "DIII-D/JET H-mode" scaling [10]. Table 2 shows predictions of the different scalings for 155 kA Ohmic regime in TUMAN-3 tokamak. Therefore the question is how to describe energy confinement in Ohmic H-mode. Either by some enhancement factor over Neo-Alcator scaling or using different expressions for instance JET/DIII-D H-mode scaling.

The study of the τ_E dependencies on input power and density was performed in the regime with a plasma current of 112 kA [11].(Fig. 4) After boronization the input Ohmic power drops by a factor of two whereas energy confinement time increases substantially This figure also indicates that the τ_E dependence on the density is weak or negligible. The Neo-Alcator scaling is also shown for comparison.

Before recent experiments has been started TUMAN-3M was boronized using Carborane (C2B10H12) deposition in He glow [12]. As a result relatively low recycling was observed in the experiments. I_p scan was performed in boronized old vessel and new vessel, but quality of the coating a new vessel was worse than in old vessel, because only one source of Carborane was used instead of two. Spectroscopic data shows decrease of Oxygen concentration by a factor of 2-3. Under this conditions we have found that τ_E became lower by a factor of 1.5. Reduction of the τ_E under poor vacuum conditions means direct influence of plasma purity on confinement. This could be seen on Fig. 5.

Comparison of the results from Ohmic H-mode confinement studies on TUMAN-3M with the DIII-D/JET scaling for ELM-free H-mode plasma shows good agreement [10]. Fig. 6 Shows that majority of the TUMAN-3M points lie near the linear approximation for three tokamaks (JET, DIII-D, ASDEX).

3. Summary

Studies of the energy confinement time in OH in TUMAN-3M showed weak dependence on density contradicting to Neo-Alcator scaling.

The transition into H-mode in ohmically heated plasma was found in a simple circular limiter configuration.

Studies of the energy confinement time in Ohmic H-mode in TUMAN-3M showed strong dependence on plasma current and on input power.

Confinement in Ohmic H-mode corresponds well to JET/DIII-D H-mode scaling.

These results help to support the conjecture that H-mode physics has common nature in tokamaks with different geometry and heating method.

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