*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-2.070 (2002)*

Observation of Improved Confinement in the Initial Phase of the Ohmic Discharge in the TUMAN-3M.

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Introduction

Confinement improvement in the plasma core was observed in many experiments with auxiliary heating [1]. In some experiments with essential electron heating or current drive the confinement improvement in the core was observed in electron component. In those experiments a positive role of negative or low magnetic shear $s=(r/q)\cdot(\partial q/\partial r)$ was established to be favourable for the internal transport barrier formation [2]. In purely ohmically heated plasma the formation of electron transport barrier is difficult because of the tie between the safety factor profile q(r) and the heat source radial distribution.

In recent experiments in the TUMAN-3M tokamak a temporal confinement enhancement in electron component was observed in the initial phase of the discharge in the ohmically heated plasma. The paper describes experimental results demonstrating the confinement improvement. The role of q(r) evolution in the observed phenomenon is discussed.

Experimental observations

The temporal improvement of electron confinement was found as a result of variation of plasma current magnitude and its increase rate under conditions of intensive gas puffing in the initial phase of a discharge. The confinement improvement was observed in deuterium plasma with the following parameters: R_0=0.53 m, a_l=0.22 m (circular limiter configuration), B_T=0.6–0.9 T, $q^{cyl}\geq 2.9$, I_p=110–140 kA, $\langle n_e\rangle=(1.2\text{–}2.0)\cdot 10^{19}$ m^{-3}, $T_e(0)$=0.35–0.6 keV. The phenomenon was first found on the soft X-ray (SXR) emission signals. Typical evolution of some plasma parameters in the regime with improved confinement is presented in Fig.1. The indication of the confinement improvement is an excess of the SXR intensity between 35ms and 43 ms over the values typical for the later phase of the discharge. The SXR intensity starts to grow in the end of current ramp up phase. The SXR intensity rise keeps on for about 10 ms and is followed by a fast drop with a time scale of about 2–4 ms.

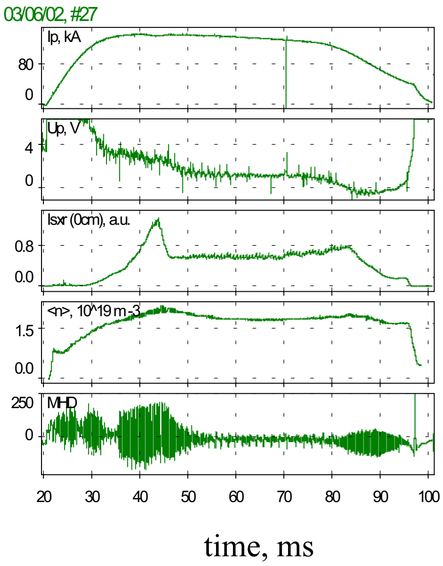

Fig. 1. Plasma parameters evolution in the discharge with improved confinement in the core. (I_p – plasma current; U_p – loop voltage; I_{SXR} – SXR intensity; <n> - central chord average density; MHD – Mirnov coil signal)

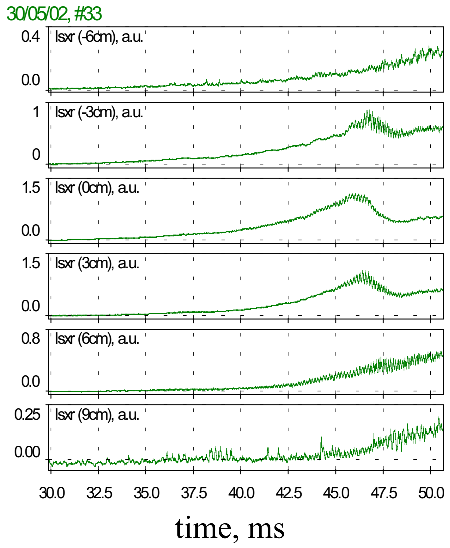

Fig. 2. Evolution of SXR emission intensity along various vertical chords.
The shift of the each line of sight relative to the vessel centre is shown in the brackets. Positive sign corresponds to the shift outwards.

Localisation of the region with improved confinement was derived from SXR intensity measurements along various lines of sight, from electron temperature profiles evolution measured by Thomson scattering and from density profiles measured by microwave interferometer. Fig. 2 demonstrates SXR emission intensity measured along 6 various vertical chords in the discharge with I_p= 130 kA. The temporal increase of the SXR intensity over the quasi-stationary level typical for the late stage of the discharge is observed on the central chords (-3 cm, 0 cm, +3 cm). Since the evolution of the SXR intensity on the more peripheral chords (±6cm, ±9cm) is monotonic, one can conclude that

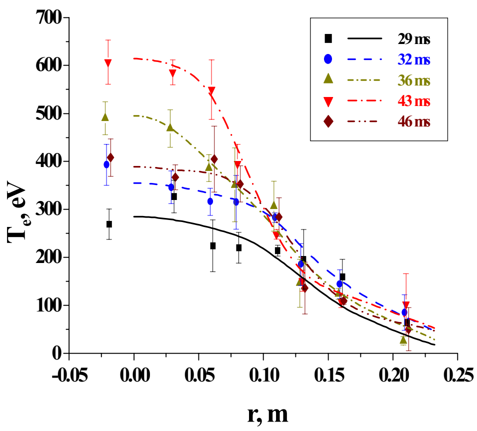

Fig. 3. Electron temperature profile evolution measured by Thomson scattering.

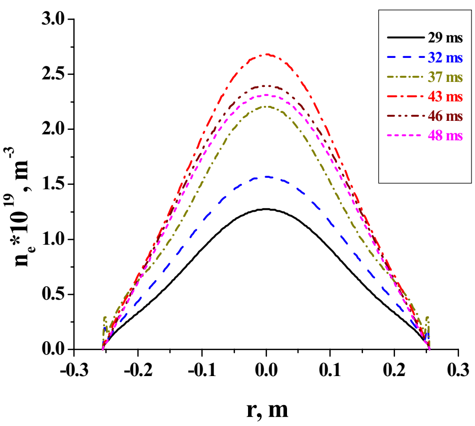

Fig. 4. Electron density profile evolution measured by microwave interferometer.

the region of improved confinement is located within r=6cm. The central localisation of the improved confinement region is also confirmed by electron temperature $T_e(r)$ and density n(r) profiles evolution presented in Figs. 3&4. The rise of the $T_e(r)$ is observed in the time period from 36 ms to 43 ms in the central part. At 43 ms the confinement degradation takes place, resulting in the fast decay of the central electron temperature: $T_e(r)$ profile at 46 ms is very similar to one measured at 36 ms. Noteworthy, the $T_e(0)$ maximum during the confinement phase is ~0.2 keV (50%) higher than $T_e(0)$ in later phase of the discharge.

Parametric Dependencies and Discussion

The safety factor evolution q(t) is found to be an important parameter for the confinement improvement in the initial phase. No confinement enhancement is observed at $q^{cyl}(a)<2.9$. The regime is sensitive to the derivative of the edge safety factor $\partial q^{cyl}/\partial t$ in the current ramp up stage. Fig.5 presents time delay t_0 between the I_p start-up and the confinement improvement onset versus edge safety factor derivative $\partial q^{cyl}/\partial t$. The delay time t_0 is normalised to the current diffusion time t_I calculated for the initial phase of the discharge (29 ms). Confinement enhancement starts earlier at higher q(a) derivative and later at smaller q(a) derivative.

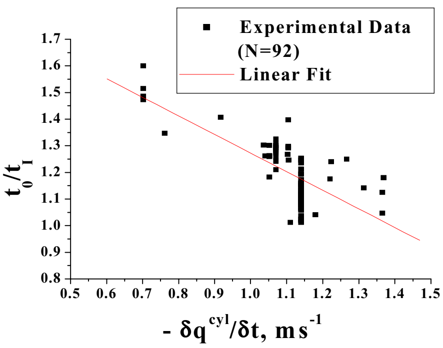

Fig. 5. Normalised delay t_0/t_I in confinement improvement start versus edge safety factor derivative $\partial q^{cyl}/\partial t$.

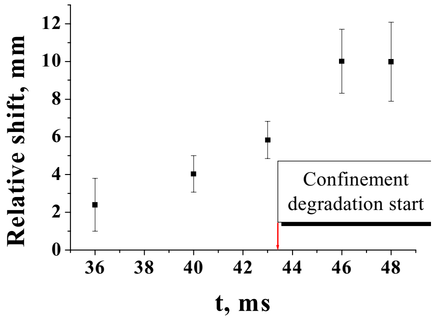

Fig. 6. Relative shift of magnetic axis in the initial stage of the discharge with confinement improvement in the core.

It was found that the SXR emission magnitude associated with the confinement improvement in the core rises with plasma average density. This may be caused by the square dependence of I_{SXR} on $<n>^2$ or by the gas puff influence on j(r). The intensive gas puff could cool the periphery, thus resulting in faster current penetration into the core. The I_{SXR} evolution becomes monotonic at average density below $1.1 \cdot 10^{19}$ m^{-3}. The attempts to increase an average density above $2.2 \cdot 10^{19}$ m^{-3} result in MHD mode locking and minor/ major disruption.

Some conclusions on the processes in plasma core can be made from consideration of the confinement degradation phase. The magnetic axis position at this stage was estimated as the position of a maximum on the SXR intensity profile. The estimation of the magnetic axis displacement is shown in Fig. 6. The graph demonstrates that during the confinement degradation the magnetic axis moves outwards on ~0.5 cm. Taking into account that Shafranov shift is proportional to $\beta_p + l_i/2$ and the electron pressure in the core at this stage essentially drops (Figs. 3 & 4), one can conclude that the confinement degradation correlates with a current density profile peaking.

The conclusion is also confirmed by the analysis of the MHD activity observed on the central (r≤6cm) SXR chords (see Fig.2). The analysis shows that just before the confinement degradation the m=1 mode develops in the central region. This is consistent with the assumption of j(r) profile peaks in this phase. Loop voltage evolution during the period of improved confinement also evidences substantial j(r) rearrangement (Fig. 1).

The I_{SXR} decrease at 43-46ms (Fig. 1) does not look like an internal disruption as the typical time scale of the I_{SXR} decay in sawtooth crash is much less (~100 μs). Furthermore, no any features characteristic for internal disruption is found on the U_p, the Mirnov coils and D_α emission during the degradation phase. Sawtooth oscillations in this regime start 2–4 ms after the improved confinement termination (see Fig. 2).

Summary

In the experiments in the TUMAN-3M tokamak the temporal confinement improvement in electron component was found in ohmically heated plasma. Maximum central electron temperature in this phase is 50% higher then $T_e(0)$ in the later phase of the discharge. It was shown that safety factor profile evolution is an essential factor influencing the confinement in this regime. The termination of the confinement improvement occurs when q=1 surface appears in the core.

Acknowledgements

This work was jointly supported by RFBR grants # 01-02-17922, #00-15-96760 and by Ministry of Industry, Science and Technology of RF grant # 01-06.

References

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