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Confinement bifurcation by magnetic compression on TUMAN-3

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INTRODUCTION

Experiments on magnetic compression on different tokamaks have shown superadiabatic increases in the plasma parameters [1-5]. The increases indicate enhancement in the energy and particle confinement in the above cases. In other experiments the increases in plasma temperature and density were lesser than adiabatic laws predict [5-8]. In the later experiments degradation of the confinement was concluded. No explanation for the difference in the plasma behavior during magnetic compression was found in [1-8].

On TUMAN-3 the both enhancement and degradation of the confinement were observed in the minor radius magnetic compression experiments [5]. The improvement occurred when the density was in the range (0.6-1.5) 10^{19} m^{-3}, and revealed itself as increases in the electron and ion temperatures and density above adiabatic law predictions. We suggest that a transition to *H* mode is the explanation of the superadiabatic improvements. Clear signatures of an *L-H* transition were found in the compression experiment [9]. Outside the critical range, i.e. at lower and higher densities in the initial plasma, the observed increases in T_e, T_i and n were below adiabatic law predictions, provided that no *L-H* transition occurred.

In this paper the results of the new study of the *L-H* transition triggered by magnetic compression are presented. The feature of the recent experiments was small compression ratio what allowed reducing power input $P_{\partial B/\partial t}$ during compression phase. The mechanism of the radial electric field E_r origin during magnetic compression is proposed to account for the *L-H* transition.

H MODE TRIGGERING BY MAGNETIC COMPRESSION

Initial plasma parameters were as follows: R_0=0.55 m, a_l=0.22 m, B_t=0.6-0.65 T, I_p=135 kA, $<n>=(1\text{-}1.5)\cdot 10^{19}$ m^{-3}, $T_e(0)$=0.4-0.5 keV, $T_i(0)$=0.1-0.15 keV. In this scenario the discharge was in the ordinary ohmic regime, if no B_t ramp up is applied, and entered the *H* mode if magnetic compression is switched on. Compression was produced by fast increase of the toroidal field on the flattop of the discharge. Compression ratio B_t^C/B_t^O was close to 1.2, B_t ramp up time was 1.7 ms. Power input from $\partial B_t/\partial t$ was less than 20% of P_{OH}. Typical temporal evolution of some plasma parameters in the above scenario is shown on Fig.1. *L-H* transition occurred on 55 ms and was indicated by substantial increase in the density with simultaneous drop in the D_α intensity. Reflectometry measurements of the edge turbulence intensity showed significant decrease in the fluctuation spectrum width during the transition [10]. It is thought that underlying mechanism of the turbulence suppression is the stabilization of fluctuations by sheared $E\times B$ flow.

According to analysis [11] the *H* mode in this scenario is triggered by a radial electric field emerging near the periphery in the presence of a strong longitudinal electric field E_φ. Peripheral E_φ is generated by the ohmic power supply as a reaction on increase in the internal inductance l_i during magnetic compression phase, see second window in Fig.1. Strong E_φ

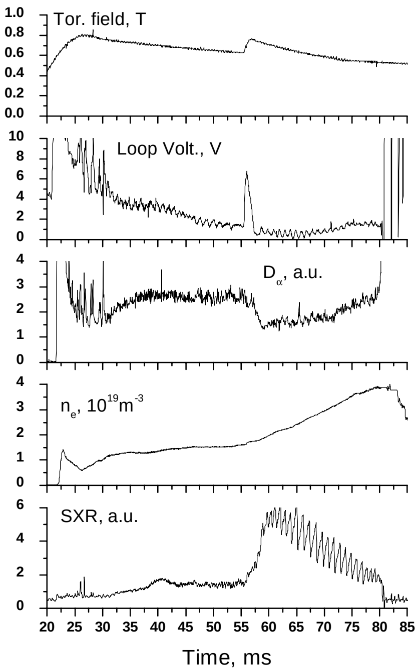

Fig. 1 Temporal behavior of the B_t, U_p, D_α emission, n_e-av, and SXR radiation in the shot with H mode triggered by magnetic compression.

causes appearance of difference in the radial drift velocities of trapped electrons and ions, and resulting in establishing of radial field calculated using revised neoclassical theory [12].

It should be mentioned that E_r generated by compression does not result in selfconsistent *H* mode state. Therefore, if the compression time is shorter than ≈1.5 ms, *L-H* transition does not occur. If the compression time is long enough (in our case ≈1.7 ms) density/pressure pedestal builds up near the periphery and selfconsistent *H* mode establishes. Gradual increase in the density pedestal clearly seen on Fig. 2. Here, one can see that the averaged along the central chord density increases to some extent during compression (maximum B_t is indicated by vertical line), whereas peripheral density does not change much. Some decrease in the transport during this stage was concluded from drop in the D_α emission and narrowing of the fluctuation spectrum [10]. Density pedestal develops only after B_t maximum is reached indicating that selfconsistent *H* mode establishes with noticeable delay. In later time the density begins to increase in more deep regions of the plasma, see second window on Fig. 2 – density averaged along chord shifted by 4.8 cm inward compared with the first window. This gradual development of the peripheral pedestal is seen on the density profiles measured during *H* mode development, see Fig. 3.

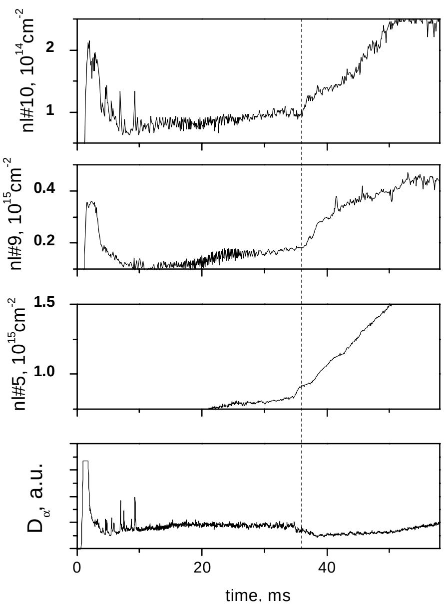

Fig. 2 Averaged density measured along chords: #10 – r=20.5 cm, #9 – r=15.7 cm, #5 – r=3.5 cm. Lower window – D_α.

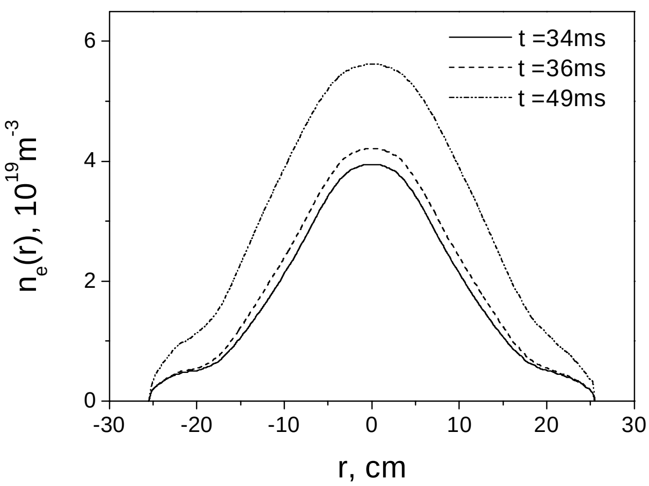

Fig. 3 Density profiles measured during H mode establishing in magnetic compression experiment.

MAGNETIC COMPRESSION OF *H* MODE PLASMA

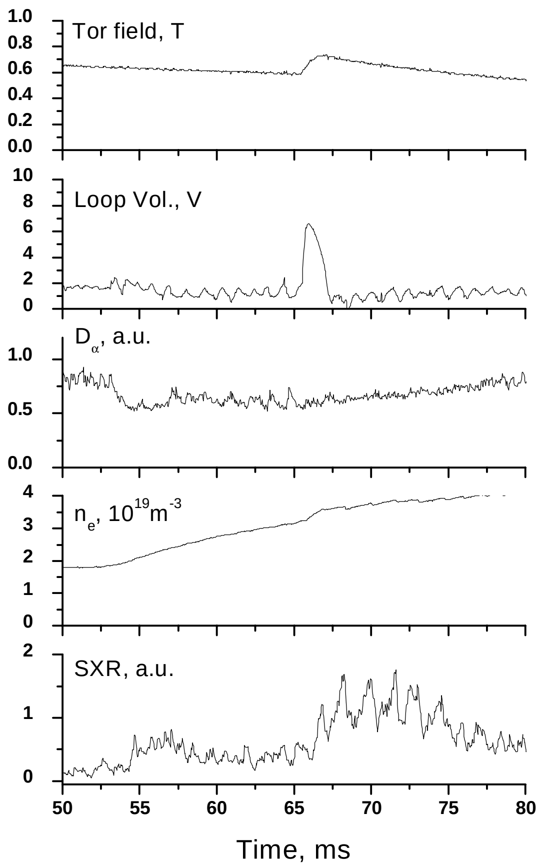

Fig. 4 Temporal behavior of the B_t, U_p, D_α emission, n_e-av and SXR radiation in the shot with magnetic compression of the H mode plasma.

Above experiments allow to conclude that magnetic compression serves as a trigger for *L-H* transition and that improvements in the plasma parameters (increase in the density and energy content, damping of the turbulent transport) are sequences of *H* mode establishing, but not the compression itself. In order to check this conclusion we perform the experiments, in which the compression was applied to *H* mode plasma. Parameters of the initial plasma and the compression setup were close to that ones described in previous section. *H* mode plasma state was achieved as result of the ohmic *H* mode establishing caused by short pulse of the working gas puff. Typical waveforms of some plasma parameters in this scenario are shown on Fig. 4. The ohmic *H* mode transition occurred on 53 ms. The signatures of the transition are pronounced change in the $\partial n_e/\partial t$, D_α drop, some increase in the SXR intensity and reduction of the turbulence spectrum width [10]. Compression was switched on 10-15 ms after the transition. In accordance with the expectations, no further improvement in the confinement was found in this case: no change in the $\partial n_e/\partial t$ following the compression, no further drop in the D_α emission, no further damping of the peripheral turbulence. Increases in the density and SXR intensity are in good agreement with calculations performed using adiabatically increased central n_e and T_e.

DISCUSSION

The observations made allow suggesting hypothesis explaining superadiabatic increase in the density and temperature in an experiment on magnetic compression. Indeed, one can assume that under the appropriate condition compression triggers *L-H* transition, thus resulting in confinement enhancement. This would result in additional (compared with adiabatic) increase in the plasma parameters. When initial conditions are far from *H* mode the transition does not happen and increase in the parameters agrees or less than adiabatic predictions. This hypothesis is in agreement with the both recent and previous results obtained on TUMAN-3 [5,8]. For TUMAN-3 device the appropriate condition for *H* mode transition is realized when density is in the (0.6-1.5) 10^{19} m^{-3} range. At lower densities transition is difficult because of strong increase in the necessary power. At higher densities TUMAN-3 plasma is in the *H* mode and further improvement in the confinement does not occur. Suggested hypothesis may be useful for analysis of the other compression experiments [1-4,6,7].

SUMMARY

The experiments with small compression ratio have shown the possibility to trigger *H* mode, although the increase in the input power was small ($P_{\partial B/\partial t}$ was less than 20% of P_{OH}). Enhancement in the confinement does not occur when initial plasma is in *H* mode. The hypothesis explaining superadiabatic increase in the plasma parameters in some compression experiments is suggested. Performed experiments support the mechanism of *H* mode triggering by a radial field generation in the presence of strong longitudinal field E_φ [11].

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