THE APPLICATION OF INTRACAVITY THOMSON SCATTERING TO THE STUDY OF FAST TRANSIENT PLASMA PROCESSES

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1. Introduction

Fast transient plasma processes are of great interest for high temperature plasma physics. They allow to study important physical phenomena which could be low manifested in steady state plasma. The experimental study of fast transient processes requires appropriate diagnostic techniques. Recently new approach to Thomson scattering based on laser multipass intracavity probing has been developed [1, 2]. It provides the measurements of evolution of electron temperature with high accuracy and repetition rates. The work reports its application to the study of lower hybrid heating of plasma in the FT-2 tokamak and analysis of first results.

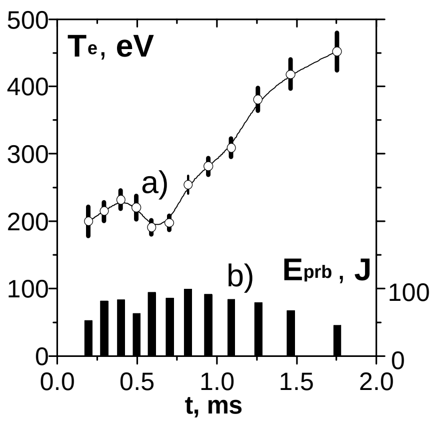

Fig.1. a) evolution of electron temperature;
b) pulse probing energy

2. Thomson scattering diagnostic system

Laser probing system in the FT-2 tokamak consists of a single ruby rod and multipass system which forces laser beam to travel 22-24 times through the plasma volume and provides about 20-fold increase of scattered radiation energy. 70-80% of the laser input energy returns from the multipass system back to the laser rod. This forms elongated laser resonator cavity of low radiation losses with plasma volume inside it and makes it possible to use a single active element in the probing system. Multipulse laser oscillation is obtained with passive Q-switch. As an example of the measurements, Fig. 1 demonstrates the rise of electron temperature after plasma disruption in a tokamak discharge. Here the repetition rate about 10 kHz and total probing energy is 930 J. The duration of the oscillation is given by the duration of the pumping. High accuracy of the measurements is achieved in spite of poor photodetectors ($\eta<1\%$) used in the system. The main technical details concerning diagnostic system and data treatment are given in [3].

3. Experimental conditions

Multipulse Thomson scattering was used in lower hybrid heating experiments in the FT-2 tokamak (R=55 cm, a=8 cm, I_P=20 kA, B_T=2.2 T) for the measurements of evolution of electron temperature and density profiles during LHH. RF power (100 kW, 920 MHz) was launched in plasma with $N_{||}$=2.5 by using a double waveguide grill. Ohmic discharge was formed in the center of vacuum vessel with central density of $2.5*10^{13}$ cm^{-3}. Under given plasma density the direct transfer of RF power to electrons due to classical mechanism is hardly possible. Therefore the electron heating was expected only from ions. RF pulse was applied between 28.6 and 33.2 ms from the beginning of the discharge. During LHH and post heating stage the equilibrium control system could not prevent significant shift of plasma column outward of the torus. This shift is clearly visible in the evolution of electron density profiles measured by microwave interferometer along major radius (Fig. 2). To make the region of magnetic axis accessible for Thomson scattering the laser probing vertical axis was shifted by 2.5 cm outward from the center of the vessel. Such arrangement and large asymmetric plasma shift violates simple relation between coordinate of temperature measurements and the radius of magnetic surface. To determine this relationship we need to know the magnetic structure in plasma. It was reconstructed from electron density profiles measured by microwave interferometer (Fig. 2) taking into account that electron density is about constant at magnetic surfaces. Furthermore all the profile are plotted versus the radius of magnetic surface.

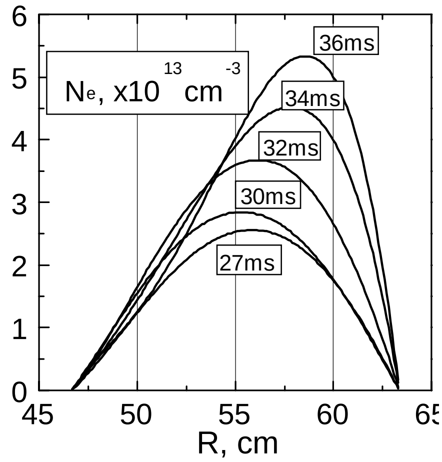

Fig. 2. Evolution of electron density profiles measured by microwave interferometer

4. **Experimental results**

In contrast to expected ion heating a significant heating of electrons was found in this regime. Electron temperature rises in the central region of the discharge (Fig. 3). It starts from the middle of RF pulse and does not stop even after RF pulse switch off (Fig.4). The rise of electron temperature is observed only in the region located inside r~5 cm. 1.5 ms later LHH start the gradient of density increases at the edge of this region. Ion temperature is increased by a factor of 3 [4] during LHH. It remains lower than electron temperature in the interior of gradient region and exceeds it outside the barrier. At post heating stage the gradient of edge ion temperature is increased by 4 times as compared with Ohmic discharge.

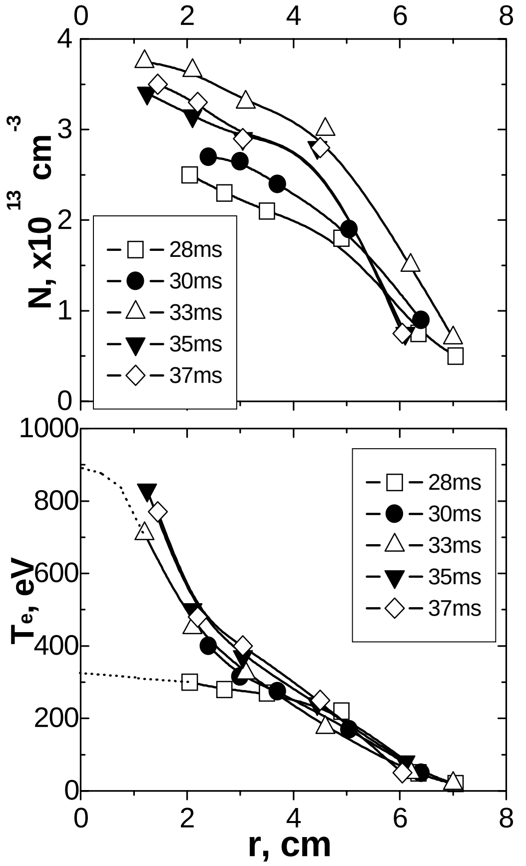

Fig. 3. Evolution of electron temperature and density profiles during LHH

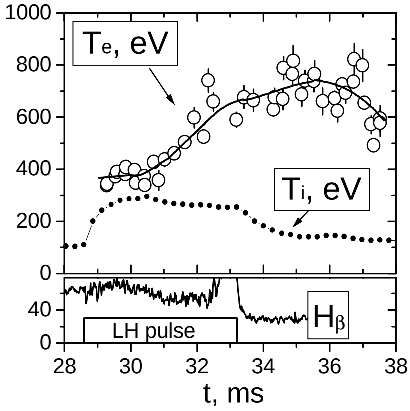

Fig. 4. Evolution of central electron and ion temperatures during LHH.

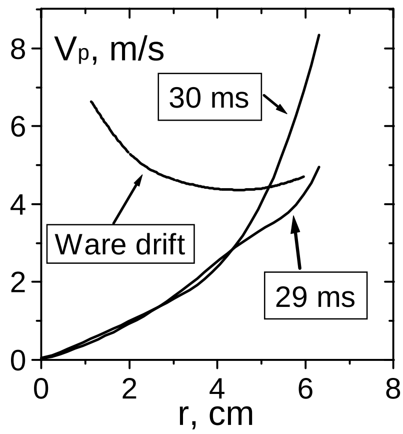

Fig. 5. Profiles of pinch velocities

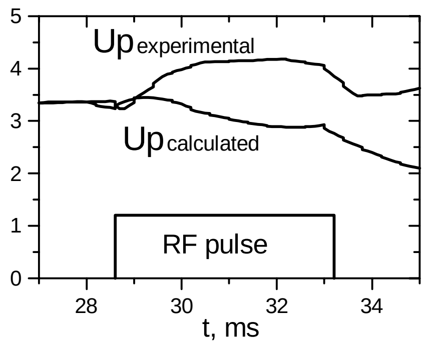

Fig. 6. Evolution of loop voltage during LHH

These features could indicate the transition of plasma into improved confinement regime caused by LHH. The drop of H_β emission (Fig. 4), especially at post heating stage, gives additional evidence for this contention. As we suppose the increase of plasma density is associated with plasma pinch velocity because there are no particle sources which could contribute significantly to the rise of plasma density in these conditions. Hydrogen source drops during LHH and the main electron sources in plasma core (CIV - CV ions) posses large ionisation time (~5 ms). Therefore the pinch velocity could be estimated from the evolution of electron density profiles (Fig. 5) at fixed particle source. Pinch appears at the start of RF pulse and rises steeply on plasma periphery at 30-31 ms. Sharp increase of central electron temperature and density barrier are observed just at this moment.

The rise of electron temperature does not followed by the drop of experimental loop voltage (Fig.6). The calculated loop voltage (assuming the absence of the pinch) drops during RF pulse and remains at this level at post heating stage. Its difference with measured loop voltage could not be explained by the increase of Z_{eff}. We suppose that it is caused by plasma pinch. Radial plasma velocity at plasma edge can be estimated from the difference ΔU between experimental and calculated loop voltage according [5]: $V_p = \dfrac{c\Delta U}{2\pi R B_P}$.

It equals to ~ 8 m/c and corresponds to the pinch velocity found from particle balance.

Here we present the results on electron energy balance inside the half of plasma column (Fig. 7) where the main electron power source (except RF power deposition to electrons) are well measured and calculated. They are shown in Fig. 7 as well. Electron energy content in this region increases from the LHH start. This rise is terminated well before the end of RF pulse. The rise of the electron energy could be resulted both improved confinement and direct absorption of RF power. Assuming no absorption of RF power by electrons and taking into account Ohmic heating, electron-ion transfer power and pinch contribution to electron energy one can find 6-fold decrease of electron thermal diffusivity χ_e.

It remains at the same level at post LH stage. This fact allows to suppose the absence of RF power absorption by electrons at the end of LHH at least. Referring the rise of the electron energy to RF power absorption one finds about 10 kW RF power contributed directly to electrons in plasma center at the start of LH pulse. Analysis Ohmic and post heating stages requires no assumptions about RF power absorption. Their comparison shows significant rise of the electron energy life time inside the half of plasma column from 0.9 ms to 2.5 ms caused by LHH.

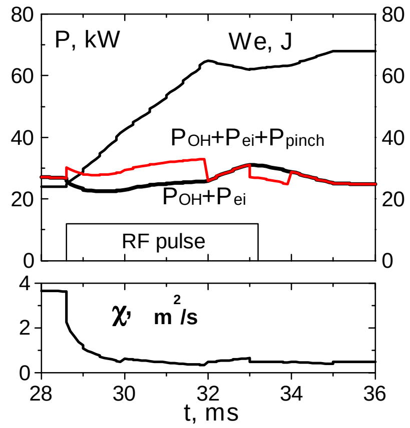

Fig. 7. Electron energy balance

This preliminary analysis of electron energy balance did not take into account equilibrium conditions in presence of large shift of magnetic surfaces which is several times greater the value estimated from measured plasma energy content. Such shift is associated with substantial increase of plasma internal inductance, i.e. the picking of plasma current density. Recently we simulate plasma equilibrium taking into account experimental shift of magnetic surfaces and found plasma current density to be concentrated in the interior half of the plasma column. The consideration of plasma equilibrium in combination with energy balance is the next step of the study of the effective LH heating in the FT-2 tokamak.

5. **Conclusion**

Experiments in the FT-2 tokamak demonstrate the transition of plasma into improved confinement caused by lower hybrid heating. The efficiency of LH heating depends strongly on the Ohmic plasma parameters [6] and mainly, as we suppose, on electron temperature. It determines the threshold of parametric decay of LH waves [4, 7] and the regime of the absorption of RF power in plasma. The study of the dynamic of energy balance in plasma is one of the powerful ways to establish physical mechanisms of the effective LH heating.

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