OBSERVATION OF THE SKIN-LIKE PROFILES OF ELECTRON TEMPERATURE AND DENSITY OF TURBULENTLY HEATED PLASMAS IN THE TRIAM-1 TOKAMAK

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OBSERVATION OF THE SKIN-LIKE PROFILES OF ELECTRON TEMPERATURE AND DENSITY OF TURBULENTLY HEATED PLASMAS IN THE TRIAM-1 TOKAMAK

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The time evolution of electron temperature and density profiles are measured on the turbulent heating experiment in the TRIAM-1 tokamak. The skin-like profiles of electron temperature and density are observed just after the application of the pulsed electric field for turbulent heating.

The width of the skin layer of the electron temperature profile is about 1 cm, and agrees well with the theoretical value.

The above mentioned skin heating of electrons just after the heating pulse is also spectroscopically confirmed by the remarkable decrease of the volume emission of visible lines which is localized at the outer plasma region.

Key Words: Tokamak Device, Turbulent Heating, Ruby Laser Thomson Scattering, Skin-Like Profile of Electron Temperature, Volume Emission of Visible Line.

1. Introduction

The further heating of fusion oriented plasmas is now in a crucial importance, and many theoretical and experimental results are reported concerning to N.B.I. heating and R.F. heating.

The turbulent heating method, which is one of the most promising alternatives with the simplicity of the heating device, is applied to the TRIAM-1 tokamak[1] and effective ion heating is already reported[2].

Recently the time evolutions of electron temperature and density profiles after the turbulent heating pulse are measured with a Ruby laser Thomson

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scattering system, and skin-like profiles of electron temperature and density are observed just after the application of the turbulent heating pulse. Moreover, by measuring the spatial and temporal evolutions of visible line emission it is clarified that the volume emissions which have low ionization potential and localized at the outer plasma region, such as H_α, Mo I and MoII, decrease remarkablly just after the application of the turbulent heating pulse.

These time evolutions of visible lines are considered to be the results of a skin heating of electron components.

In this report, we describe the observation of the skin-like profiles of electron temperature and density of turbulently heated plasmas in the TRIAM-1 tokamak.

2. Experimental Apparatus

In Fig. 1 the schematic diagram of the apparatus is shown.

The device parameters of TRIAM-1 are as follows, the major radius $R=25.4$ cm, the limiter radius $a=4$ cm and the maximum toroidal magnetic field $B_T=40$ kG.

A Ruby laser Thomson scattering system, a Neutral Energy Analyzer, a 2 mm μ-wave interferometer and visible spectrometers are equipped as shown in Fig. 1. The molybdenum limiter is set at the exhausting port.

The spectroscopic and neutral energy analyzing measurements are made horizontally by scanning the line-of-sight vertically and the electron temperature measurement is made vertically scanning on the plasma mid-plane.

3. Experimental Results

At 3 msec after the initiation of an ohmically heated tokamak plasma

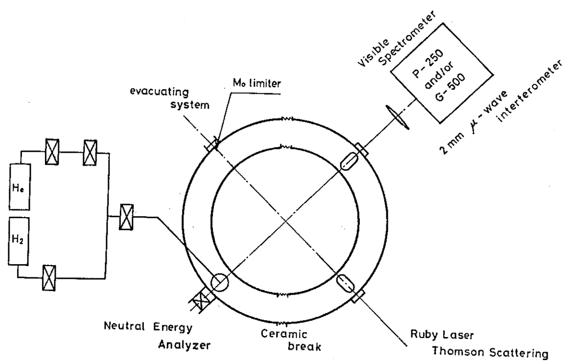


Fig. 1 Schematic diagram of experimental apparatus.

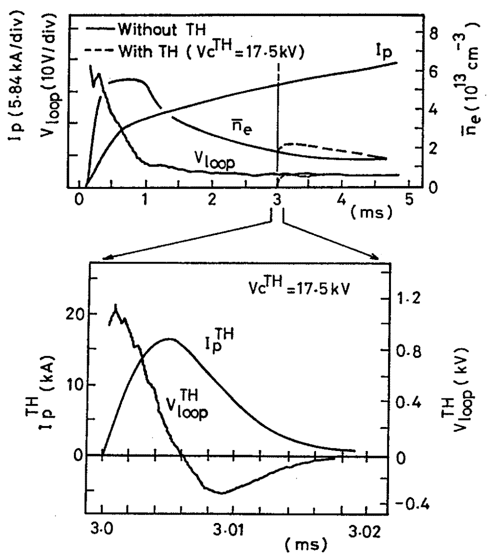


Fig. 2 Time evolutions of plasma current I_p, loop voltage V_{loop} and line-averaged electron density $\bar{n}_e$, and current I_p^{TH} and voltage V_{loop}^{TH} wave-forms of applied pulse for turbulent heating.

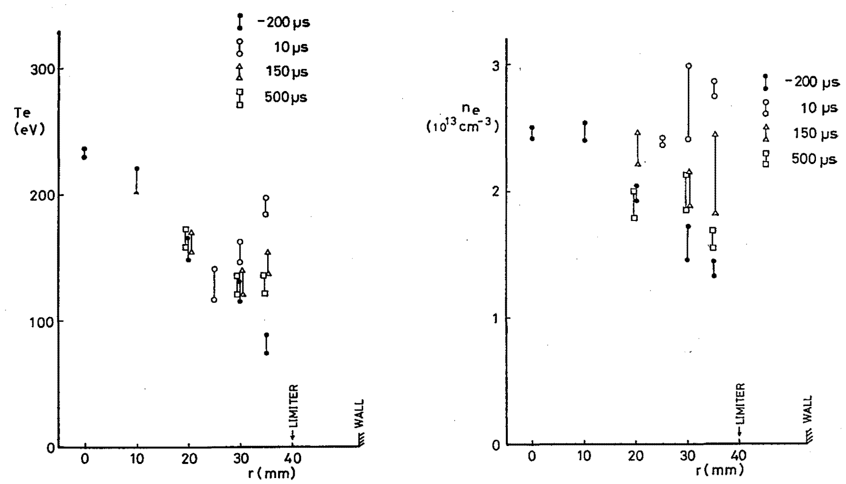
the turbulent heating pulse is applied. The plasma parameters just before the heating pulse are plasma current $I_P=20\text{kA}$, central elctron teemperature $T_e(0)=230\,\text{eV}$, central ion temperature $T_i(0)=120\text{eV}$, line-averaged electron density $\bar{n}_e=1.8\times10^{13}\text{cm}^{-3}$ and toroidal field $B_T=31\text{kG}$.

Fig. 2 shows the time evolutions of plasma current I_p, loop voltage V_{loop} and line-averaged electron density $\bar{n}_e$, and the current I_P^{TH} and voltage V_{loop}^{TH} wave-forms of the applied pulse for turbulent heating.

In Fig. 3 are shown the time evolutions of the profiles of electron temperatue $T_e(r)$ and the electron density $n_e(r)$ measured by a Ruby laser Thomson scattering system. At 10μsec after the application of the heating pulse, the electron temperature at $r=35$ mm is heated from 80 eV to 190eV, and the skin-like profile of electron temperature with 1 cm thick is clearly observed. At 150μsec after the heating pulse the electron temperature at $r=35$ mm decreases to 140 eV, but slight increase from 145 eV to 155 eV is observed at $r=20$ mm. At 500 μsec after the heating pulse the temperature profile has only a plateau at the plasma periphery.

Now we estimate the width of the above mentioned skin layer.

On this experimental condition, the ratio of the characteristic angular frequency of the pulsed field for turbulent heating (ω) to the effective electron-ion collision one (ν_{ei}) is $\omega/\nu_{\text{ei}}\leq0.2$ in the outer plasma region just before the turbulent heating pulse.



(a) (b)

Fig. 3 Time evolutions of the distribution profiles of electron temperature $T_e(r)$ and electron density $n_e(r)$.
(a) Temperature profiles. (b) Density profiles.

Therefore, the skin width δ can be estimated by the following equation,

$$\delta \cong (2/\mu_0\hat{\sigma}\omega)^{1/2}(1-\omega/2\nu_{ei}) \cong (2/\mu_0\hat{\sigma}\omega)^{1/2}$$

where $\hat{\sigma}$ is the electrical conductivity averaged over the skin layer, i.e., $\hat{\sigma}=\int_{a-\delta}^{a} \sigma(r)\cdot 2\pi r dr/(2\pi a\delta)$. We adopt the radial profile $\sigma(r)=\sigma_0[1-(r/a)^2]^3$, and obtain $\hat{\sigma} \cong 2\sigma_0(\delta/a)^3$. We can derive the relation to determine the skin width δ as $\delta \cong [a^3/(\mu_0\sigma_0\omega)]^{1/5}$.

The value of δ is about 0.9 cm and agree well with that of observed one.

The slight decrease of loop voltage V_{loop} after the heating pulse shown in Fig. 2 seems to be due to this electron heating.

By the application of the heating pulse, the electron density increases steeply at the plasma periphery, and then decreases slowly to the level without the heating pulse. This increase in electron density is consistent with the line-averaged electron density $\bar{n}_e$ measured by the 2 mm μ-wave interferometer. (Fig. 2). The above mentioned increase in electron density can be explained by the following reasons, i.e, ionization of the residual hydrogen gas at plasma periphery by plasma heating and/or impurity influx caused by the interaction of plasma with the limiter and the vacuum wall due to the application of the turbulent heating pulse.

Figure 4 shows the time evolutions of the experimental line radiance of H_α. From this figure we see the remarkable increase of the radiance just after the heating pulse, and succesive decrease down to the value lower than

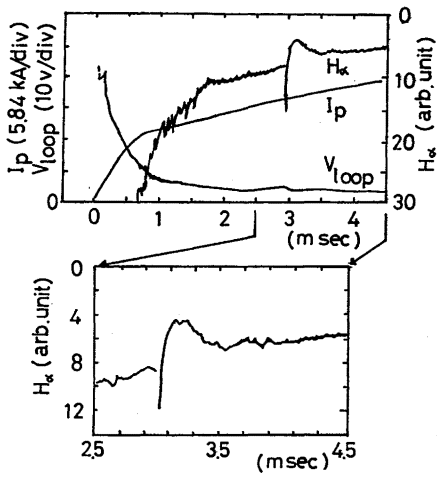


Fig. 4 Time evolution of the experimental H_α radiance. (The line-of-sight chord height of $H=10$ mm.)

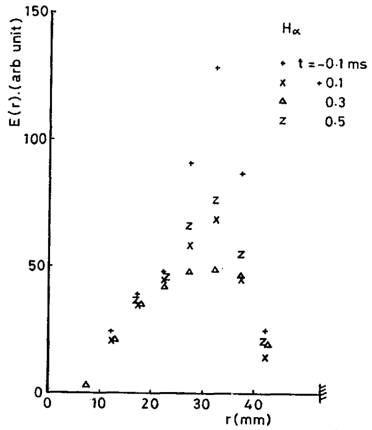


Fig. 5 Abel-inverted volume emission $E(r)$ of H_α 6562.8 A. At $t=0$ the turbulent heating pulse is applied and the sign $-$ ($+$) expresses before (after) the application of the heating pulse.

that of the case without the heating pulse. This decrease of line radiance is considered to be the results of skin heating of electron component.

At about 400 μsec after the heating pulse, the line radiance has recovered to the level of the case without the heating pulse.

In Fig. 5 the Abel-inverted volume emission $E(r)$ of H_α line is shown, and above mentioned decrease of line radiance is clearly shown at plasma periphery.

The other lines of low ionization potential such as Mo I and Mo II show similar behaviours. But as for the visible lines of moderate and high ionization potential, of which volume emission is localized rather inner plasma part, such as OIV and OVI, this decreasing behaviour of the experimental radiance lower than that of the case without the heating pulse never occurred, and this may be due to the impurity influx caused by the interaction of plasma with the vacuum wall.

4. Conclusion

At the turbulent heating experiment in TRIAM-1, the skin-like profiles of electron temperature and density are observed by a Ruby laser Thomson scattering measurement, and these skin-like profiles are also confirmed spectroscopically.

The ionization of the residual hydrogen at plasma periphery and impurity influx due to the rapid heating of plasmas are considered to be the reason for the density skin-like profile.

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