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ION TEMPERATURE MEASUREMENTS OF TURBULENTLY HEATED TRIAM-1 PLASMAS BY THE DOPPLER-BROADENING OF VISIBLE LINES.

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The ion temperature of the turbulently heated TRIAM-1 plasma is obtained from the Doppler-broadening of visible lines.

The radial profiles of the volume emission of visible lines are beforehand measured to examine whether the volume emissions are localized at a specified position of the minor cross-section of the plasma or not. The ion temperature of the specified position is determined from these profiles.

The time behaviour of thus obtained Doppler ion temperature shows a good agreement with that of the one derived from the Neutral Energy Analyzer.

Key Words: Ion Temperature Measurement, Doppler Broadening, Turbulent Heating, Tokamak Device.

1. Introduction

In many tokamaks, the neutral beam injection heating and wave heating in various frequency range are made, and many theoretical and experimental results are reported. But these heating methods have many unsolved physical and technical problems.

The turbulent heating method is one of the most promising alternatives because of the simplicity and minimization of the heating system.

In the TRIAM-1 tokamak[1], the short current pulse has been applied to the high temperature tokamak plasma and the effective bulk ion heating has been observed without a macroscopic plasma destruction[2].

The ion temperature has been measured by the Neutral Energy Analyzer[3], and it is important to confirm the bulk ion heating by the other diag-

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nostic method.

From the above mentioned reason, the Doppler broadening of visible lines are measured and the bulk ion heating is spectroscopically confirmed.

The specrtal lines used in this experiment are H_α and He II. The radial distributions of their volume emission are measured to examine the localization of their emission intensity at a specified position of plasma minor cross-section or not. By thus obtained profiles of the volume emission, the ion temperature of specified position is derived.

This report describes the time evolution of Doppler ion temperature of the turbulently heated plasma and the comparison with that of deduced from the Neutral Energy Analyzer measurement.

2. Experimental Apparatus

The TRIAM-1 tokamak is a high field tokamak with large B_T/R value of about 16. The major radius and limiter radius are $R=25.4$ cm and $a=4$ cm respectively. The plasma parameters obtained are the central electron temperature $T_e(0)=640$ eV, the central ion temperature of ohmically heated $T_i(0)=280$ eV, line-averaged electron density $\bar{n}_e=2.2\times10^{14}\,\mathrm{cm}^{-3}$ and the current density $j_p=950\mathrm{A/cm}^2$.

The schematic diagram of the experimental apparatus is shown in Fig. 1. The visible spectrometers used are Nikon P-250 (which has focal length of 250 mm and 1200 grooves/mm grating with 500 nm blaze) and G-500 (focal length of 500 mm and 1200 grooves/mm grating with 300 nm blaze).

The spectral lines from He impurity ions are not strong enough to get the wavelength-resolved intensity, and a bit of pure He impurity is artificially mixed to the hydrogen gas to raise the He spectral line intensity. But a careful attention is made not to add too much He impurity to affect the plasma characteristics.

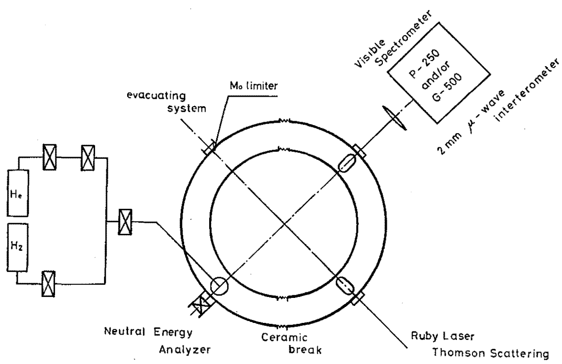


Fig. 1 Schematic diagram of the experimental apparatus.

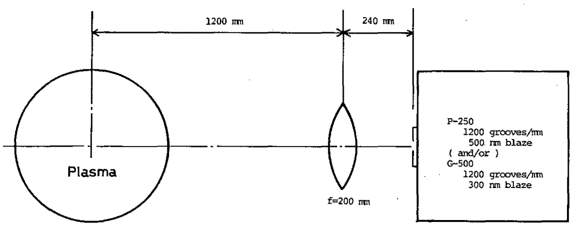


Fig. 2 Optical arrangement of the spectrometer system.

3. Estimation of the Ion Temperature from Doppler-Broadening.

The Doppler full width of half maximum λ_D is expressed as

$$\lambda_D = 7.7 \times 10^5 \lambda (T_D/A)^{1/2}$$

where λ is the central wavelength of the measured line in A, T_D is the Doppler ion temperature in eV and A is the atomic weight of the emiting ion.

Let the measured full width of half maximum be λ_M and the instrumental full width be λ_I, the Doppler full width λ_D is expressed by the following relation,

$$\lambda_D{}^2 = \lambda_M{}^2 - \lambda_I{}^2$$

Then the Dopple rtemperature is expressed as

$$T_D = T_M - T_I$$

where T_M is the measured apparent temperature and T_I is the equivalent instrumental temperature.

The value of λ_I or T_I was beforehand deduced by measuring the full width of half maximum of Hg lines.

4. Experimental Results.

The Doppler broadening measurements were made on the turbulently heated hydrogen plasmas with toroidal field of 31 kG.

The Doppler broadening measurements were made horizontally with scanning the line-of-sight chord vertically.

In Fig. 3 the time evolutions of the plasma current I_p, loop voltage V_{loop} and line-averaged electron density $\bar{n}_e$, and the current I_p^{TH} and the voltage V_{loop}^{TH} wave-forms of the turbulent heating pulse are shown. The plasma parameters of ohmically heated plasma just before the application of the turbulent heating pulse are as follows, plasma current $I_p = 20$ kA, line-averaged

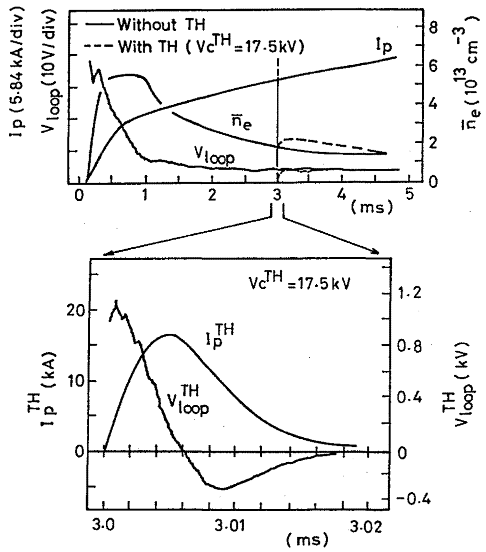


Fig. 3 Time evolutions of the plasma current I_p, loop voltage V_{loop} and line-averaged electron density $\bar{n}_e$, and current I_p^{TH} and voltage V_{loop}^{TH} wave-froms of applied pulse for turbulent heating.

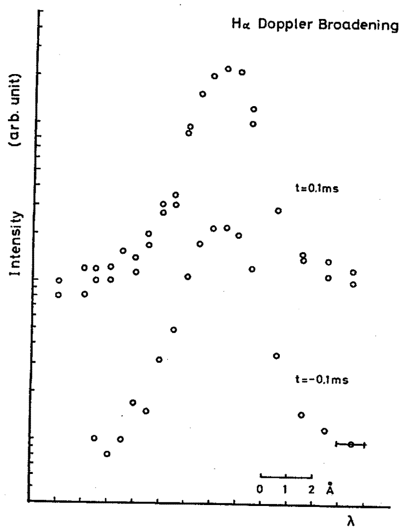


Fig. 4 Line profiles of H_α before ($t=-0.1$ ms) and after ($t=0.1$ ms) the application of turbulent heating pulse. At $t=0$ the heating pulse is applied.

electron density $\bar{n}_e=1.8\times10^{13}\text{cm}^{-3}$, central electron temperature $T_e(0)=230\text{eV}$ and the central ion temperature $T_i(0)=120\text{ eV}$. And at 3 msec after the initiation of this ohmic plasma the turbulent heating pulse is applied.

In Fig. 4 line profiles of H_α are shown, and it is easily seen that H_α lines are symmtrically broadened to both-wavelength sides.

Figure 5 shows the observed broadening of HeII 4685.7 A line.

Figure 6 shows the time evolutions of ion temperature determined from the Doppler broadening of visible lines together with that of deduced from

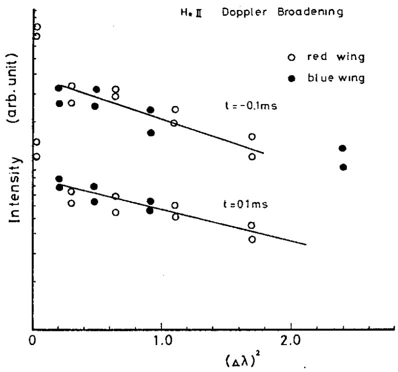


Fig. 5 Observed broadening of He II 4685.7 A before ($t=-0.1$ms) and after ($t=0.1$ms) the application of turbulent heating pulse.

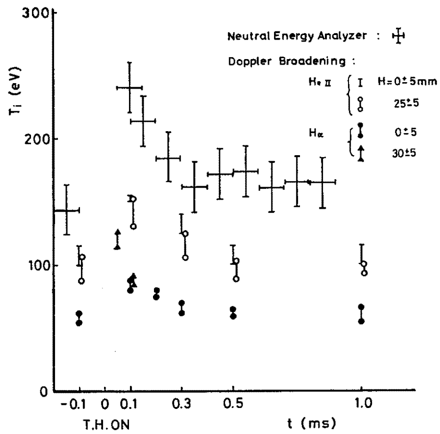
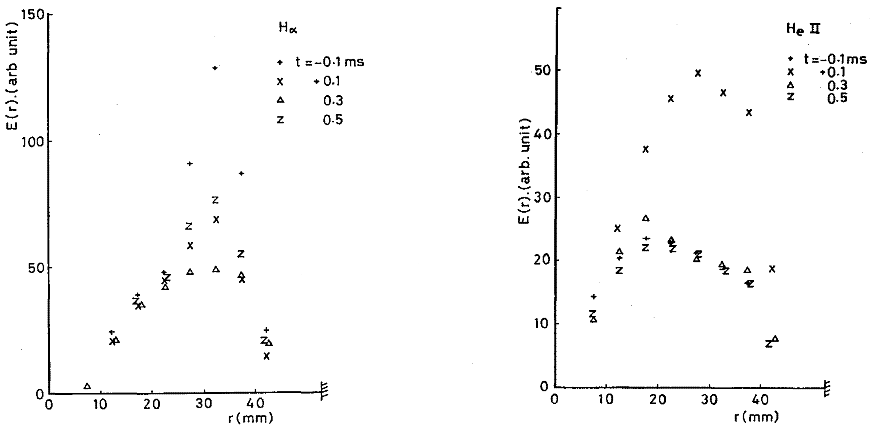


Fig. 6 Time evolution of ion temperature determined from the Doppler-broadening and that of deduced from N. E. A. measurement. In this figure H represents the line-of-sight chord height from plasma center.



(a) (b)

Fig. 7 Time evolution of radial profiles of volume emission $E(r)$ obtained after Abel-invesiron.
(a) H_α 6562.8 A. (b) He II 4785.7 A.

the N.E.A. measurements.

Now it is required to determine the radial position of which ion temperature is obtained from Fig. 4 and Fig. 5.

The time evolutions of radial profiles of volume emission of H_α and HeII lines obtained after Abel-inversion (assuming cylindrical symmtry) are shown in Figs. 7(a) and 7(b). It is easily seen that the volume emission of H_α line localizes at the plasma periphery, but those of HeII line have comparatively flat profiles.

From Fig. 7(a) it can be considered that the Doppler ion temperature determined from the broadening of H_α line expresses the characteristic temperature at $r \approx 32.5$ mm, and this is also clearly confirmed from the fact that the ion temperature obtained from the Doppler broadening at different line-of-sight chord height (H=25 mm) agree well with that of obtained at H=0 mm.

However the ion temperature determined from the Doppler broadening of HeII line at different line-of-sight chord height does not show the agreement with each other. From the consideration of the radial profiles of volume emission of HeII line, it can be considered that the ion temperature determined from the data obtained from the line-of-sight chord height H=25 mm express the real temperature at $r=25$ mm, and that of H=0 mm express the averaged ion temperature at $r=10 \sim 25$ mm.

It should be noted that the temperature relaxation times between protons and impurity ions (or H_0) is estimated to be about 100μ sec for HeII ions (5 μsec for H_0). Therefore, the ion temperature derived from the Doppler broadening of HeII and H_α lines are considered to show the temperature of protons at specified positions.

5. Conclusions

The ion temperature of turbulently heated plasmas in TRIAM-1 is obtained from the Doppler broadening of the visible lines (HeII and H_α).

The effective ion heating all over the plasma cross-section by the turbulent heating method is thus spectroscopically confirmed, and from the decaying characteristics of thus obtained Doppler ion temperature the decay time of ion energy is estimated, and a good agreement with that of deduced from neo-classical theory is obtained.

The spectral lines used were H_α and HeII, which have their localized emission peaks at rather outer portion of plasma minor cross-section, and the central ion temperature was not obtained in this experiment.

Acknowledgement

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