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Electron Temperature Measurement by Thomson Scattering in a Low-Aspect-Ratio RFP RELAX

低アスペクト比RFP装置RELAXにおけるトムソン散乱を用いた電子温度計測

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A Thomson scattering diagnostic system has been developed for measuring electron temperatures in a low-aspect-ratio reversed-field pinch (RFP) plasmas in REversed-field pinch of Low-Aspect-ratio eXperiment (RELAX). In the range of plasma currents I_p = 50–80 kA, the central electron temperature was around 100 eV. To estimate the central electron pressure p_{e0}, a density calibration was performed from simultaneous measurements with a 104-GHz microwave interferometer. In the higher current region, p_{e0} tended to saturate, which may be improved by optimizing minute control of equilibrium in the higher current region.

1. Introduction

The reversed-field pinch (RFP) is one of the magnetic confinement systems for high β plasmas. In the RFP, toroidal magnetic field for plasma confinement can be lower by an order of magnitude than in the tokamak. Therefore the RFP concept is attractive from economical commercial fusion reactor. Recent experiment in Madison Symmetric Torus (MST) RFP, they succeeded in achieving the largest total β of ~28% using the techniques of inductive current profile control known as Pulsed Parallel Current Drive (PPCD) and pellet injection [1].

The neoclassical bootstrap current is another important issue for sustaining the RFP configuration in steady state. Some equilibrium analyses have shown that, if β of 20–30% is achieved in the aspect ratio A = 2 equilibrium, the bootstrap fraction of 20–30% is expected [2-3]. The bootstrap fraction increases by lowering A and increasing the total β. It is one of the research topics in RELAX (R/a = 0.5m/0.25m; A = 2) experiment [4] if we could identify the bootstrap current directly in high β plasmas.

The electron temperature is one of the fundamental parameters to estimate plasma confinement. The Thomson scattering diagnostic is the most reliable method to measure the electron temperature in high-temperature fusion plasmas. We have developed a Thomson scattering diagnostic system for RELAX. We will report the electron temperature and associated electron β behaviors in RELAX.

2. Experimental Setup

The electron temperature is measured with a Thomson scattering diagnostic in RELAX. It is a single point measurement in time at the center of the vessel. Figure 1 shows the Thomson scattering diagnostic system. In the polychromator, the scattered light was divided into four-wavelength regions (four channels), and an avalanche photo diode (APD) was used to measure the light intensity for each channel.

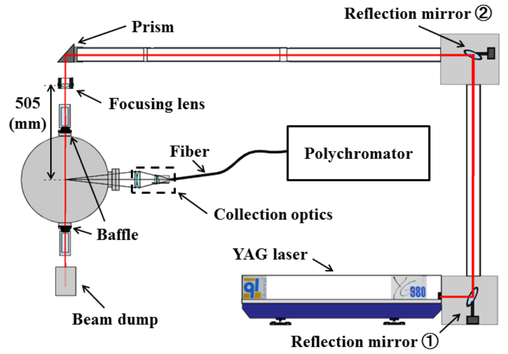

Fig.1. Schematic of the Thomson scattering diagnostic system for RELAX

3. Experimental Results

Figure 2 shows the time evolution of the central electron temperature T_{e0} in a standard I_p ~50-kA discharge. Time evolution of T_{e0} has been obtained from shot-by-shot measurements, and the error bar is standard deviation. T_{e0} at each time is the ensemble average over 20–30 identical shots. Typical value of T_{e0} is ~ 70 eV at t = 0.5 ms into the discharge, and slightly higher than 100 eV at t = 1.0 ms, keeping almost unchanged or slightly decreasing during the flat-topped phase.

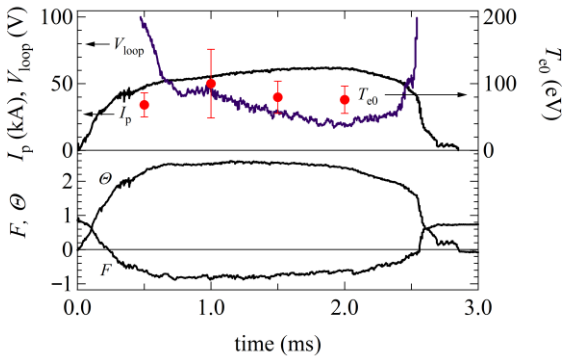

Fig.2. Time evolution of central electron temperature in typical deep-reversal RFP plasma in RELAX

4. Electron poloidal beta in RELAX

For the electron density, 104-GHz microwave interferometer data were compared with the Thomson scattering data to obtain a density calibration coefficient for Thomson scattering data [5]. If we compare the total light intensity with simultaneously measured line-averaged electron density, then we can estimate a density calibration coefficient for Thomson scattered light intensity. In the density region $n_e < 1.6\times10^{19}$ m^{-3}, we can identify a linear trend. Any shift in the magnetic axis from the geometrical center, caused by a Shafranov shift for example, would easily cause a discrepancy in the linear relationship between the local and line-averaged densities. Because Raman and Rayleigh scattering calibration are yet to be done the Thomson scattering system in regard to the density behavior.

In the present analysis, we have approximated the relation as linear, defining the slope as the calibration coefficient for estimating the central electron density n_{e0}. Note that the calibration coefficient includes an uncertainty of 30%. Adopting this calibration procedure, we estimated the central electron pressure $p_{e0} = n_{e0}k_BT_{e0}$, where k_B is the Boltzmann constant.

Figure 3 shows the relation between the central electron poloidal beta β_{pe0}, defined by the ratio of central electron pressure to the edge magnetic pressure $B_{\theta a}{}^2/2\mu_0$, and electron density normalized to the Greenwald density n_G, where $n_G = I_p/\pi a^2$ with density in 10^{20} m^{-3}, toroidal plasma current I_p in MA, and a in m. β_{pe0} increases with density up to ~15% in the present experimental regime of $n/n_G < 0.35$. No saturation trend is observed, which indicates higher density operation may lead to higher β_{pe0}.

If we assume that the ion contribution to total β is comparable to that of electrons, β is expected to be higher than 20%. The RELAX plasmas reached the parameter region where sizable fraction (20–30%) of the bootstrap current may play some roles in equilibrium profiles. In addition to the equilibrium reconstruction method, a direct estimate of the bootstrap current is under way by experimental estimates of turbulent electro-motive force terms in generalized Ohm's law.

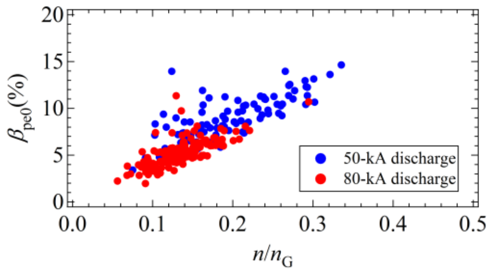

Fig.3. Relation between β_{pe0} and normalized density.

5. Summary

The central electron temperature was measured with Thomson scattering diagnostic in RELAX. The temperature increases with toroidal plasma current with scatter arising from density dependence. The central electron poloidal beta increases with density up to ~15% at the density of 35% of the Greenwald density. Estimates of the bootstrap current fraction are in progress.

Acknowledgments

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