COMPARATIVE STUDIES OF A SPHERICAL TOKAMAK AND A CONVENTIONAL TOKAMAK: MAGNETIC TURBULENCE-INDUCED TRANSPORT

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Abstract

The paper reports experiments on turbulence-induced transport in plasmas with aspect ratios A of 1.4 ~ 2.5 in a single machine. There is little aspect ratio dependence in electrostatic fluctuations. The relative levels of magnetic fluctuations in the core region are 0.01% and 0.05% for A = 1.4 and 2.5, respectively. The electron heat transport estimated from the magnetic fluctuation level of 0.01% is 0.2 kW/m^2, which is less than 2% of the electron heat flux of 13 kW/m^2 estimated from the global power balance. Thus in spherical tokamaks, the present results show that magnetic fluctuations are not responsible for electron heat transport, as in conventional tokamaks.

1. INTRODUCTION

The spherical tokamak (ST) is a candidate for a high β advanced reactor. The high β performance of the Small Tight Aspect Ratio Tokamak (START) experiment is outstanding [1]. However, the research field of the ST is quite new and there is little experimental work on turbulence-induced transport in STs. The physics of fluctuation-induced particle and heat transport is one of the key issues for the second generation STs, such as the Mega Amp Spherical Tokamak (MAST) and the National Spherical Torus Experiment (NSTX). Our main motivation for studying the physics of fluctuation-induced transport in STs is, firstly, transport optimization to obtain information for the second generation ST, and secondly, comprehensive understanding of the confinement physics of toroidal plasmas, including conventional tokamaks, stellarators and reversed field pinches. We have observed turbulence suppression and transport reduction in the presence of a sheared flow in the JFT-2M tokamak [2]. We have also measured fluctuations and electron heat transport in the Reversed Field Pinch University of Tokyo Experiment (REPUTE-1) RFP plasmas [3]. The Tokyo Spherical Tokamak (TST) has been constructed to investigate the basic physics of plasma confinement and stability in the small aspect regime [4].

2. TST-M PLASMA

The center-post of TF coils (24 MI cables of 12 mm diameter) and the OH solenoid of 50 turns of TST have been replaced by new TF coils and an OH solenoid of 200 turns to provide a higher toroidal field and larger volt seconds. The cross section of TST-M is shown in Fig. 1(a); the TF coils are located entirely inside the vacuum vessel except for the connection points, to avoid arcing problems. The experiments have been carried out in this new configuration (TST-M [5]). There are two sections of 5 mm thick aluminum shell on the inboard side and top and bottom aluminum shells (4 sectors each) of 10 mm thickness to avoid vertical instability. Typical operation parameters of TST-M are as follows: major radius R=30~38 cm, minor radius a=15~29 cm, aspect ratio A=1.3~2.5, toroidal field in the center of

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the vacuum vessel, B_{t0} =0.16~0.3 T, plasma current I_p =20~150 kA with OH flux swing of 20 mVs. The discharge duration is up to 7 ms with a loop voltage of 2 V. He glow discharge cleaning (16 hours) and titanium flash (3 hours) were performed for wall conditioning.

A variety of operation modes have been tried to obtain the aspect ratios of A=1.3 ~ 2.5, by combinations of increasing or decreasing OH flux, induction coil current ramp-up or ramp-down. The outermost magnetic flux surface is obtained using a filament model for the plasma current and the external field coil currents; input data are the signals of the flux loops surrounding the plasma and magnetic pickup coils. A typical example of the decreasing OH flux + induction coil current ramp up operation is shown in Fig. 1(b). Figure 2 shows a typical example of the long discharge duration operation. The plasma current of 22 kA is obtained with the loop voltage of 2 V (at the current flat top). The aspect ratio is 1.5 in this case. The plasma current of 150 kA is obtained by applying the induction coil current ramp up on the OH plasma. The discharge duration is short in the high current mode. The electron temperature measured by a triple Langmuir probe is in the range of several tens of electronvolts. The line-averaged electron density measured by a 50 GHz interferometer is in the range of 10^{19} m^{-3}.

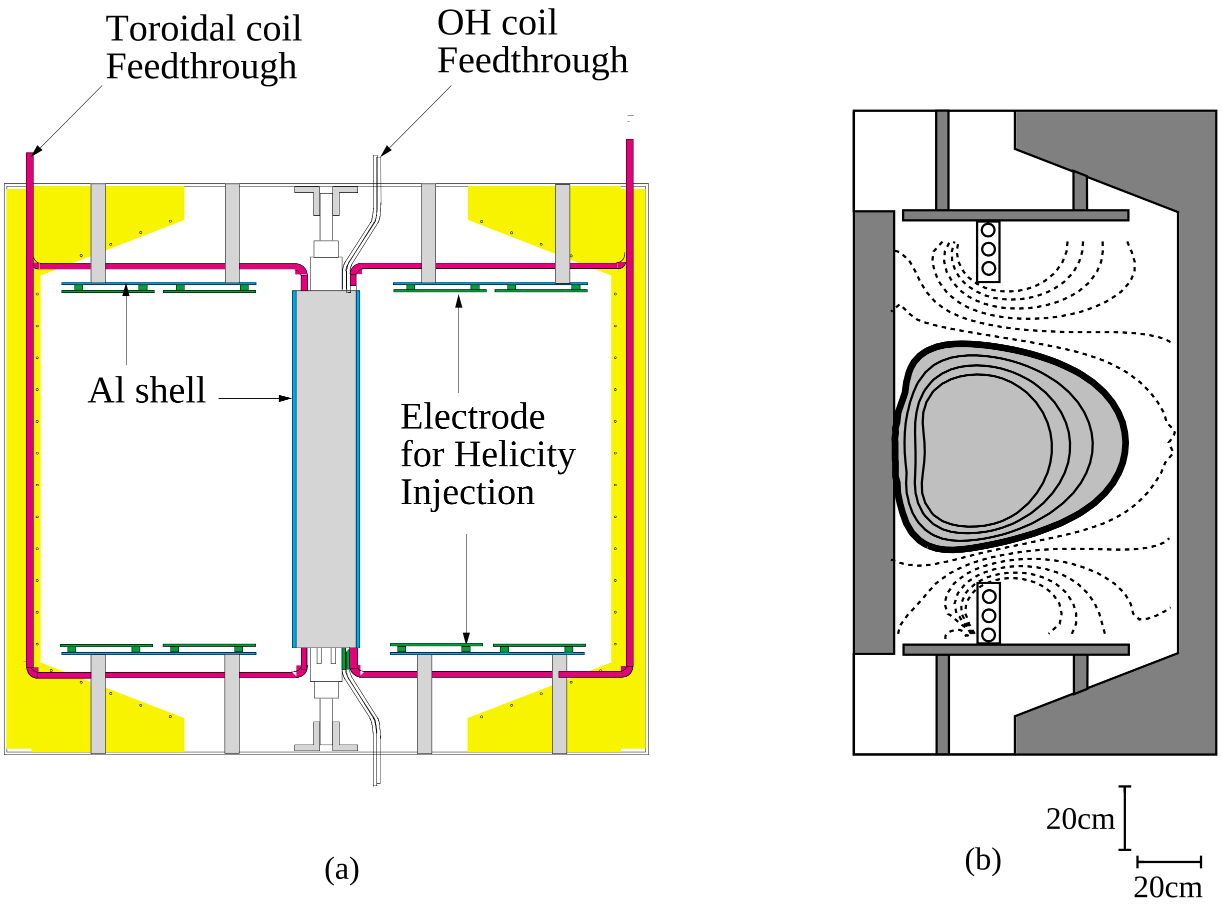

FIG. 1. (a) Cross-sectional view of TST-M; (b) magnetic flux surface of the decreasing OH flux + induction coil current ramp up operation. The gray areas show the center post, outer support structures and shells.

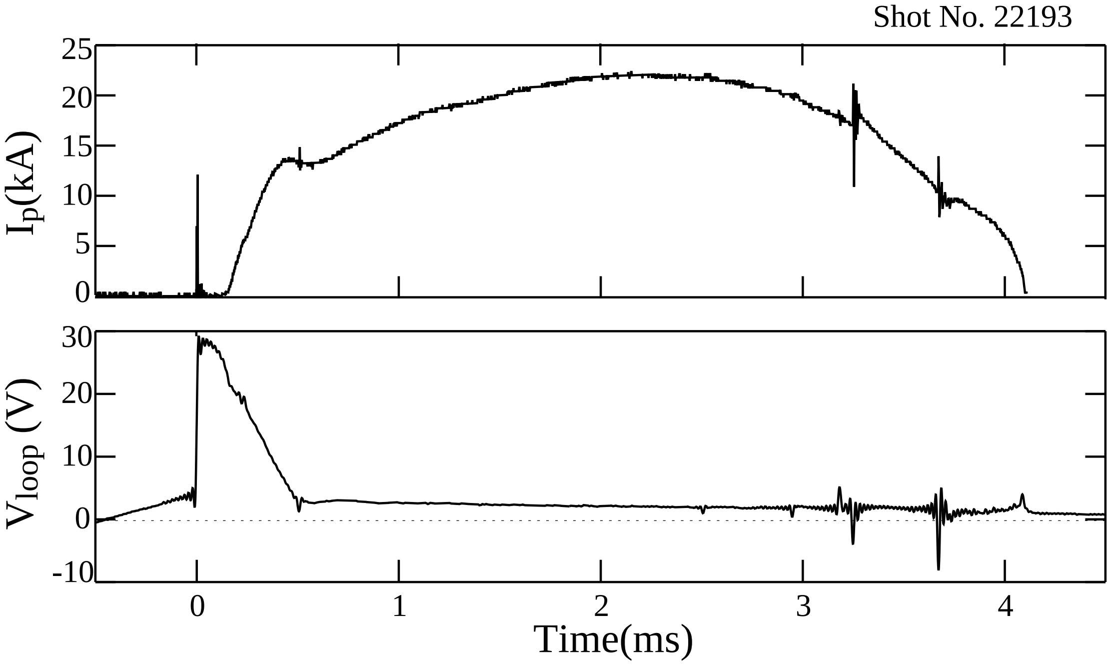

FIG. 2. Plasma current and loop voltage of the decreasing OH flux operation

3. MAGNETIC AND ELECTROSTATIC TURBULENCE

Fluctuations have been measured in cases of aspect ratios A of 1.4, 1.8 and 2.5. Triple Langmuir probes and magnetic pickup coils are mounted on the equatorial plane. They can be moved radially from the outboard side to the centerpost. The toroidal field is $B_{t0} = 0.18$ T. The plasma current Ip is 90 kA, 40 kA and 30 kA for A= 1.4, 1.8 and 2.5, respectively.

The relative level of the electrostatic fluctuations measured by triple Langmuir probes is 5-10% in the core region, then increases gradually to 20% in the outer region and at the edge jumps to 60%. There is little aspect ratio dependence.

The radial profiles of the relative fluctuation levels of the magnetic field measured by inserting the pickup coils are shown in Fig. 3. The Br fluctuation level for A=1.4 is 0.01% and much lower than the level of 0.05% for A=2.5, at nearly the same magnetic Reynolds number. Nevertheless, quantitative comparison of fluctuations between a ST and a conventional tokamak is difficult because of wall effects and different q profiles. Our largest concern now is how the magnetic fluctuation deteriorates the electron heat transport in the ST, because of higher plasma current and lower toroidal field in the ST compared with conventional tokamaks, as in RFPs. In the REPUTE-1 RFP plasma, the magnetic fluctuation level is 1-3%, which is responsible for electron heat transport [3]. The electron heat transport using Rechester-Rosenbluth heat transport theory [6] and the observed fluctuation level of 0.01% for A=1.4 is 0.2 kW/m^2, which is less than 2% of the electron heat transport of 13 kW/m^2 estimated from the global power balance. Thus in STs, our present results show that magnetic fluctuation is not responsible for electron heat transport, as in conventional tokamaks. The magnetic fluctuations will be reduced in hotter plasmas due to a higher magnetic Reynolds number so that magnetic fluctuations will not have dominant effects on electron heat transport in the next generation ST.

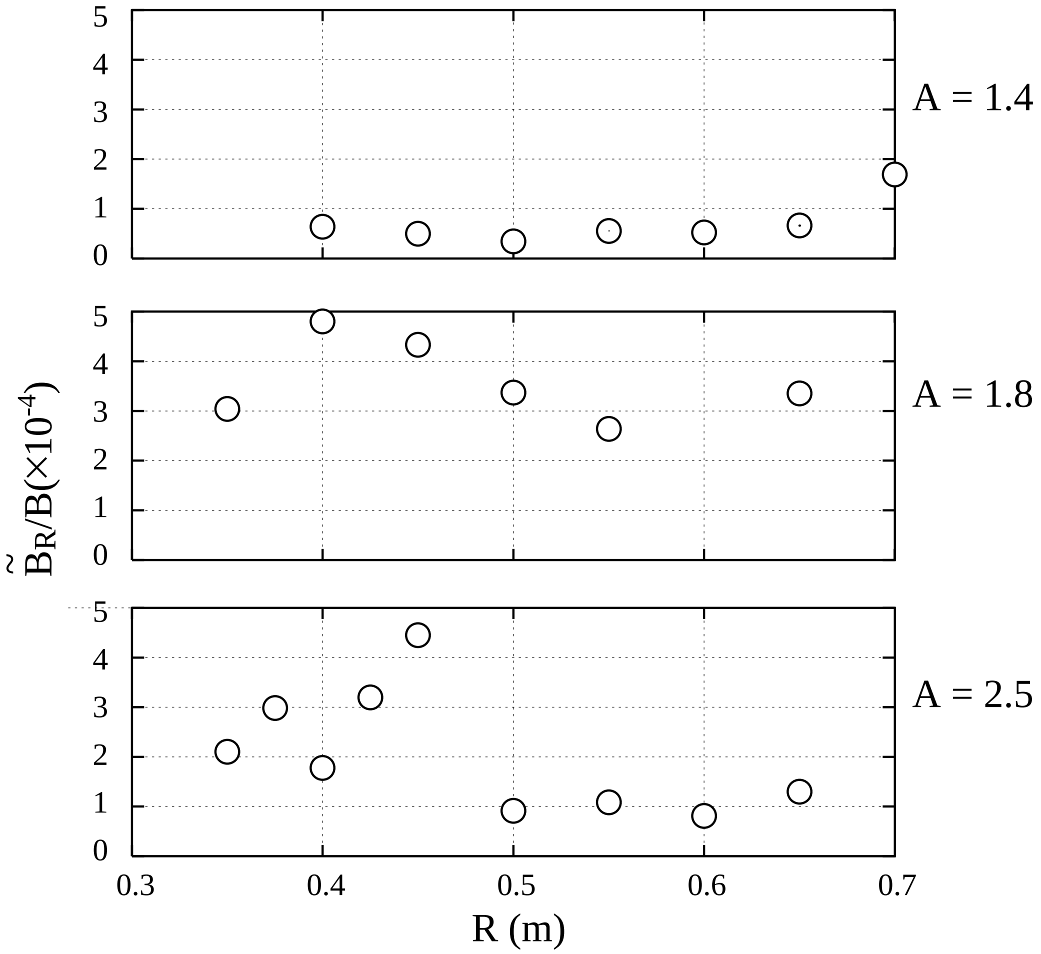

FIG. 3. The radial profiles of the relative fluctuation level of the radial magnetic field.

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