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Final Technical Report on DOE Grant for **Modeling of Plasma Rotation in the National Spherical Torus Experiment**

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This is the final technical report on the Modeling of Plasma Rotation in National Spherical Torus Experiment (NSTX) DOE Grant No. DE-FG02-02ER54679. The research subjects, technical abstracts, and publications where details of the research results can be found are reported here.

I Research Subjects and Publications

The main research effort supported by this grant is to study the momentum confinement and its consequences on particle and energy confinement in National Spherical Torus Experiment (NSTX) specifically and spherical tori and tomakaks in general. The momentum confinement deals with the plasmas rotation speed that is determined from the momentum balance equations and momentum sources. The key ingredient in the momentum equation is plasma viscosity. We have developed such a theory for spherical tori. The theory, as it is, is incomplete. More work is planned for the future. We also developed a theory for controlling the stability of the magnetic islands by pellet injection. This theory remains to be tested in experiments. The results of the research are published in referred journals and international fusion conferences. The subjects of the research and the technical abstracts of the results are listed as follows:

1. K. C. Shaing, and M. Peng, 'Transport theory for potato orbits in an axisymmetric torus with finite toroidal flow speed,' Phys. Plasmas **11**, 3726 (2004).

Transport theory for potato orbits in the region near the magnetic axis in an axisymmetric torus such as tokamaks and spherical tori is extended to the situation where the toroidal flow speed is of the order of the sonic speed as observed in National Spherical Torus Experiment. It is found that transport fluxes such as ion radial heat flux, and bootstrap current density are modified by a factor of the square of the toroidal Mach number. The consequences of the orbit squeezing are also presented. The theory is developed for a parabolic (in radius *r*) plasma profile. A method to apply the results of the theory for the transport modeling is discussed.

2. W. Zhu, S, A, Sabbagh, R. E. Bell, …, K. C. Shaing, et al., 'Observation of Plasma Toroidal-Momentum Dissipation by Neoclassical Toroidal Viscosity,' Phy. Rev. Lett. **96**, 225002 (2006).

In this work, the analytic formula for the neoclassical toroidal plasma viscosity is evaluated using the plasma parameters of NSTX to compare the calculated and the measured toroidal flow damping rate in NSTX. Good quantitative agreements between these values are obtained.

3. K. C. Shaing, S. A. Sabbagh, and M. Peng, 'Neoclassical toroidal viscosity for an axisymmetric toroidal equilibrium with multiple trapping of particles,' Phy. Plasmas **14**, 024501 (2007).

In this work, the fact that in spherical tori such as NSTX there can be multiple trapping is taken into account in calculating the neoclassical toroidal plasma viscosity. The finite aspect ratio effects are also included in the ν regime where the effective collision frequency is much less than the poloidal $\boldsymbol{E} \times \boldsymbol{B}$ drift frequency of the trapped particles using a model collision operator that includes energy scattering. Here, $\boldsymbol{E}$ is the radial electric field, and $\boldsymbol{B}$ is the magnetic field.

4. K. C. Shaing, W. A. Houlberg, and M. Peng, 'Controls of magnetic islands by pellet injection in tokamaks' Phys. Plasmas **14**, 07250 (2007).

The appearance of magnetic islands in tokamaks degrades plasma confinement. It is therefore important to control or eliminate the growth of the islands to improve the performance of a tokamak. A theory is developed to control magnetic islands using the localized pressure gradient driven bootstrap current by injecting pellets at the O-point of the island to create a peaked plasma pressure profile inside the island. This localized bootstrap current replenishes the missing equilibrium bootstrap current density that causes the island to grow in the first place. It is shown that the effect of the localized bootstrap current tends to reduce or eliminate the original drive for the growth of the island in the island evolution equation. The theory is also valid for the localized bootstrap current created by localized heating, but with much less effectiveness.

5. K. C. Shaing, M. S. Chu, S. A. Sabbagh, and M. Peng, 'Critical toroidal rotation profile for the stability of the resistive wall modes in tokamaks.' Proceedings of IAEA Fusion Energy Conference 2008, TH/P9-30.

In this work, we intend to develop an analytic theory that determines a critical toroidal plasma rotation profile for the stability of the resistive wall modes in tokamaks. To determine a critical toroidal rotation profile, we must consider two or more toroidally coupled ideal modes with resistive wall outside plasma boundary by assuming an existing plasma current density profile. We have derived a dispersion relation for three toroidally coupled modes with a resistive wall located outside plasmas. Our work is not yet completed at the end of the funding period. We will resume the work at a later date. The results on the dispersion relation of three toroidally coupled modes have been presented in conferences and meetings.

II Conclusions

The momentum confinement is one of the most important research topics related to toroidal plasma confinement devices. This research topic was initiated by the PI in 1980s. Here, we carried out more works on this topic that are relevant to spherical tori. Obviously, there are more works to be done in this area in the future.