

## Electron Heat Transport Analysis of Low-Collisionality Plasmas in the Neoclassical-Transport-Optimized Configuration of LHD

MURAKAMI Sadayoshi, YAMADA Hiroshi, WAKASA Arimitsu<sup>1)</sup>, KUBO Shin, NARIHARA Kazumichi, TANAKA Kenji, INAGAKI Shigeru, MORITA Shigeru, IDA Katsumi, MIYAZAWA Junichi, IDEI Hiroshi, WATANABE Kiyomasa, FUNABA Hisamichi, YOKOYAMA Masayuki, MAASSBERG Hening<sup>2)</sup>, BEIDLER Craig D.<sup>2)</sup>, ITOH Kimitaka, YAMAZAKI Kozo, KANEKO Osamu, KOMORI Akio, MOTOJIMA Osamu and LHD Experimental Group

National Institute for Fusion Science, Toki 509-5292, Japan

<sup>1)</sup>Graduate School of Engineering, Hokkaido University, Sapporo 060-8628, Japan

<sup>2)</sup>Max-Planck-Institut fuer Plasmaphysik, EURATOM Ass., D-17491 Greifswald, Germany

(Received 8 August 2002 / Accepted 3 September 2002)

Electron heat transport in low-collisionality LHD plasma is investigated in order to study the neoclassical transport optimization effect on thermal plasma transport with an optimization level typical of so-called “advanced stellarators”. In the central region, a higher electron temperature is obtained in the optimized configuration, and transport analysis suggests the considerable effect of neoclassical transport on the electron heat transport assuming the *ion-root* level of radial electric field. The obtained experimental results support a future reactor design in which the neoclassical and/or anomalous transports are reduced by magnetic field optimization in a non-axisymmetric configuration.

**Keywords:** neoclassical transport, optimization, heat transport, long-mean-free-path, heliotron, LHD

Reduction of the neoclassical transport is one of the key issues in the development of a reactor based on a helical system. Recent LHD [1] and CHS [2] experimental results have shown effective plasma performances in the “inward shifted” configurations, where the ideal MHD stability analysis predicts instability. These facts suggest that the MHD stability problem may not be a severe one for high-beta plasma confinement in heliotrons, and makes it reasonable to consider shifting the magnetic axis further inwards in the LHD where further improvement of the neoclassical transport is expected. In this paper, we show an optimized configuration of the LHD to a level typical of so-called “advanced stellarators”, and demonstrate experimentally the effect of neoclassical transport optimization on the thermal plasma transport.

We first study the neoclassical transport numerically for LHD configurations in which the

magnetic axis has been shifted radially. Figure 1 shows the mono-energetic transport coefficient evaluated by

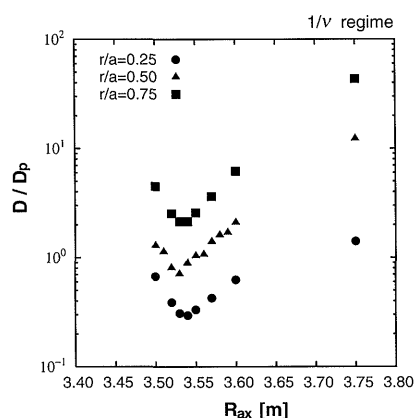


Fig. 1 Normalized neoclassical transport coefficients evaluated by DCOM as a function of the magnetic axis position in the  $1/\nu$  regime.

author's e-mail: murakami@nifs.co.jp

the DCOM code [3] normalized by the plateau value of the equivalent circular tokamak,  $D_p$ . With respect to  $1/\nu$  transport, the optimum configuration is found when the magnetic axis has a major radius of 3.53m. In this case, the effective helical ripple is very small, remaining below 2% inside 4/5 of the plasma radius [4]. This indicates that a strong inward shift of the magnetic axis can optimize the neoclassical transport of the LHD configuration to a level typical of so-called “advanced stellarators” [5].

The thermal plasma transport in the long-mean-free-path regime ( $1/\nu$  regime) is investigated to clarify the optimization effect on the neoclassical transport in the LHD. The electron heat transport coefficients are compared by shifting the magnetic axis position,  $R_{ax}$ . Figure 2 shows a comparison of electron temperatures obtained by the Thomson scattering system (center) and the effective electron transport coefficients (right) in the two configurations ( $R_{ax} = 3.53$  m [s32303] and 3.6 m [s32123]) with nearly the same density profile (left). We set the magnetic field strength so that the heating deposition profile ( $r/a < 0.2$ ) is similar in the two configurations. We cannot see a clear difference in the electron temperature in the region  $r/a > 0.5$ , though a higher electron temperature and the reduction of the effective electron heat transport coefficient,  $c_e$ , are observed in the central region ( $r/a < 0.4$ ) in the  $R_{ax} = 3.53$  m configuration case.

Next, we analyze the neoclassical transport using the DCOM code to show the role of neoclassical transport. In this experiment there is no measurement of the radial electric field,  $E_r$ , so as a first step we evaluated the neoclassical transport coefficient assuming  $E_r = 0$ . Because the  $E_r$  effect on  $\chi_e$  is relatively small

with the  $E_r$  amplitude of the *ion-root* level (open square [3]: Fig. 2, right), which is usually observed in LHD except in the case with the ITB-like steep electron temperature gradient. If the plasma is in the electron root regime, a high positive radial electric field (several tens kV/m) is expected, and the neoclassical transport coefficient becomes one order of magnitude smaller than the experimental value (open circle [3]: Fig. 2, right). The radial electric field will be measured and its effects will be clarified in the near future. Even in this electron-root case, we can emphasize that the anomalous transport in addition to neoclassical transport is reduced in the neoclassical-transport-optimized configuration of the LHD.

In conclusion, the experimental results in low collisionality plasmas show a higher electron temperature and better confinement in the neoclassical-transport-optimized configuration. The  $\chi_e$  value around the steep temperature gradient roughly agrees with the neoclassical transport value with the assumption of a zero radial electric field or ion-root regime. This demonstrates that the neoclassical and/or anomalous transports can be reduced by magnetic field optimization in a non-axisymmetric system, which gives rise to the prospect of future reactors.

- [1] H. Yamada *et al.*, Plasma Phys. Control. Fusion, **43**, A55 (2001).
- [2] S. Okamura *et al.*, Nucl. Fusion **39**, 1337 (1999).
- [3] A. Wakasa *et al.*, J. Plasma Fusion Res. SERIES, Vol. **4**, 408 (2001).
- [4] S. Murakami *et al.*, Nucl. Fusion **42**, L19 (2002).
- [5] C.D. Beidler and W.N. Hitchon, Plasma Phys. Control. Fusion **36**, 317 (1994).

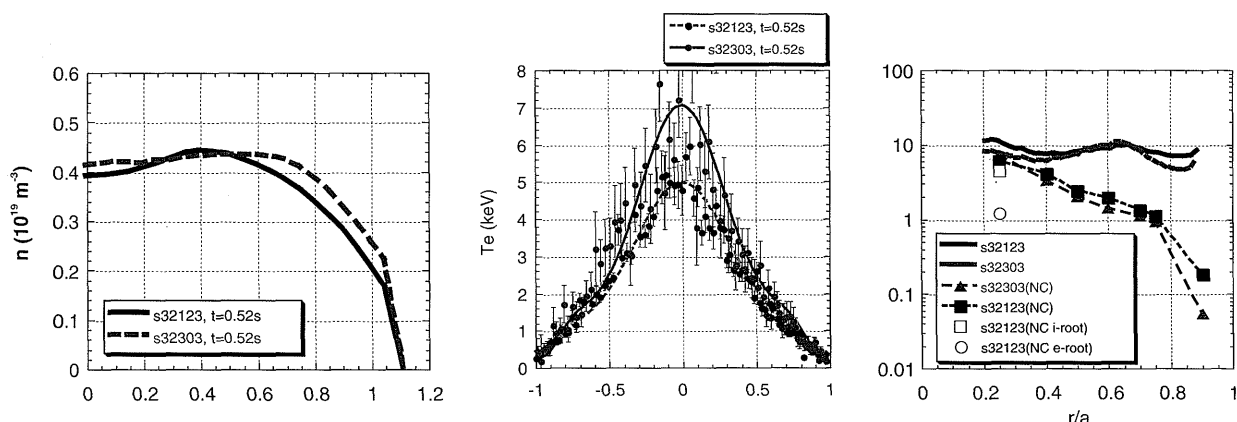


Fig. 2 Comparisons of the radial profiles of the density (left), the electron temperature (center), and the effective electron heat transport coefficient (right). The neoclassical transport coefficients evaluated by DCOM are also plotted.