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Effect of resonant magnetic field by periodically distributed TFC current on equilibrium

周期的に配分されたトロイダルコイル電流による共鳴磁場が平衡へ及ぼす影響

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Since an edge localized mode (ELM) with large amplitude is predicted to induce unacceptable heat load to plasma facing components, ELMs should be suppressed or controlled for DEMO reactor. Application of resonant magnetic perturbations (RMPs) by using internal or external coils is proposed to stochastize edge magnetic field structure for the ELM control. However, it is difficult to put such coils close to plasma due to high neutron fluence. We have proposed a new method to produce RMPs by using toroidal field coils (TFCs) where coil currents are periodically distributed. A few percentages of the increase-decrease rate of TFC distributed current with toroidal period N=3 can make stochastic magnetic field structure that is equivalent to those by perturbation coils.

1. Introduction

Toward DEMO reactor with high-β plasma, steady-state operation schemes with realistic technology and materials should be established. In particular, plasma facing components to withstand steady-state and transient heat loads are well developed. Moreover, operation scheme to avoid unacceptable heat load are also explored. As for transient heat load, an excessive heat load induced by an edge localized mode (ELM) with large amplitude is one of the major concerns for ITER as well as for DEMO. To suppress or mitigate large ELMs, application of resonant magnetic perturbations (RMPs) by using internal or external coils is proposed [1]. This is based on changing magnetic field structure at edge region, thus, stochastization of the magnetic field line. This idea is proposed in current tokamaks and it seems to be promising method to affect ELM behavior [2-4]. However, the RMP method by using perturbation coils close to a plasma is thought to be difficult in DEMO because the installation of coils in DEMO due to high neutron fluence. Namely, a property of conductor materials could be changed by neutron irradiation that causes metal embrittlement.

Therefore, we have proposed a new method to produce RMPs by using toroidal field coils (TFCs) where coil currents are periodically distributed. A few percentages of the increase-decrease rate of TFC distributed current with toroidal period N=3 can make stochastic magnetic field structure that is equivalent to those by perturbation coils.

2. RMP by using TFC

Ideally, a magnetic structure of tokamak confinement is axisymmetric structure, thus 2D structure. In practice, discrete toroidal field coils (TFCs) make rippled magnetic fields corresponding to the number of TFCs, thus TF ripple. Usually, periods of TF ripple in the current tokamaks are around 20. Such a higher period of magnetic structure cannot drastically change magnetic structure at plasma region. If the different currents can periodically flow in TFCs, it makes additional ripple with other period. Figure 1 shows an example of additional ripple field of N=3. Here, TFCs are grouped into two sets with the different currents. Note that JT-60SA design parameters are used for calculations in

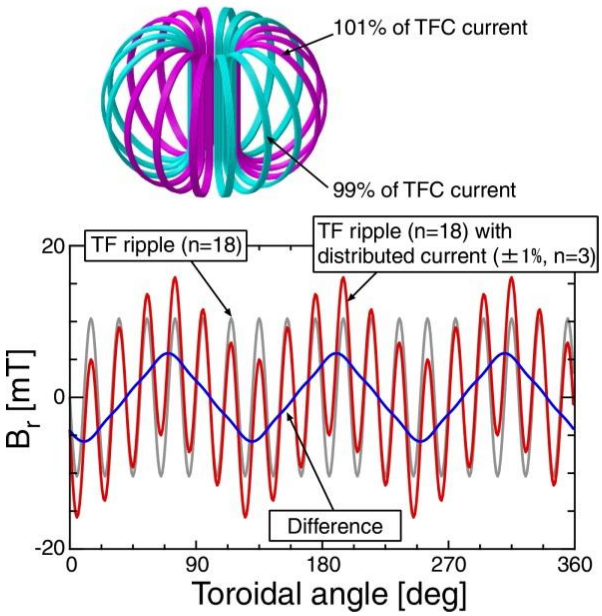

Fig.1 TFCs with periodically distributed currents of ±1% and radial magnetic field B_r vs toroidal angle at outer mid-plane.

this paper [5]. Radial component of magnetic field as a function of toroidal angle is shown. It is found that periodically distributed current of ±1% can produce radial magnetic field with an amplitude larger than 5mT that is comparable to magnetic field produced by perturbation coils [6].

3. Magnetic field structure at edge region

In order to evaluate how much the RMPs from the TFC distributed currents can affect magnetic structure at edge region, the magnetic field line tracing has been conducted. In these calculations, 3D fields are simply superposed to 2D equilibrium fields, that is, the vacuum approximation. Figure 2 shows Poincaré plots of magnetic field lines with the TFC distributed currents of ±1 and ±3% cases. As increasing the increase-decrease rate of TFC distributed currents, magnetic islands corresponding to rational surfaces grow and finally, magnetic structures become stochastic due to overlapping of neighboring magnetic islands. As shown in Fig. 2, stochastic magnetic structures appear around the normalized minor radius $\rho \sim 0.99$ and 0.94 with the cases of ±1 and ±3%, respectively. For ELM control, the pedestal region might be stochastic. Here, the pedestal region for this calculation is $\rho \geq 0.95$. This result shows that a few percent of the increase-decrease rate of TFC distributed currents, at least, can produce stochastic structure at the pedestal region.

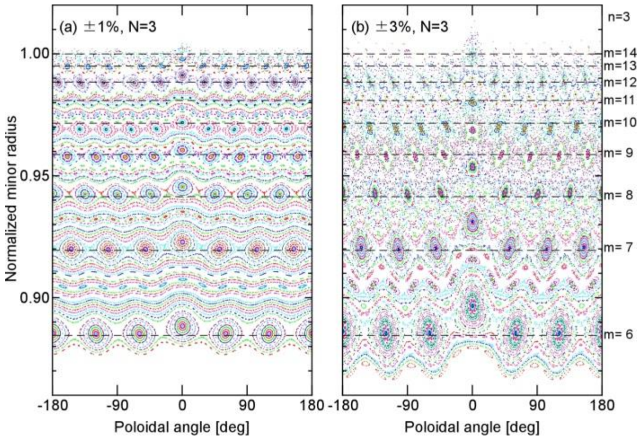

Fig.2 Poincaré plots of magnetic field lines with TFC distributed currents of ±1 and ±3% cases.

4. Fast ion loss

Since a fast ion orbit is sensitive to magnetic structure, we have calculated orbits of fast ion from the neutral beam injectors by F3D-OFMC [7] with taking into account 3D magnetic field due to the TFC distributed currents. How much the fast ion orbits are affected is evaluated from the total fast ion loss. Figure 3 shows comparison of fast ion loss rates for TFC distributed currents of 0, ±1, ±2, ±3, ±4 and ±5% cases and the EFCC currents of 10, 20 and 30kA cases. Here, the EFCC is in-vessel coil in JT-60SA for error field corrections [6]. In the case of TF ripple only case, the total fast ion loss rate is 2.6%. As increasing the increase-decrease rate of TFC distributed currents, the loss rates are also increased. Also, the dependence of the total fast ion loss on the EFCC currents is similar to that of the TFC distributed currents. Namely, the EFCC current of 10kA case is equivalent to the TFC distributed current between ±1 and ±2% cases. Note that almost all lost fast ions are originated from the fast ions deposited at the stochastized edge region

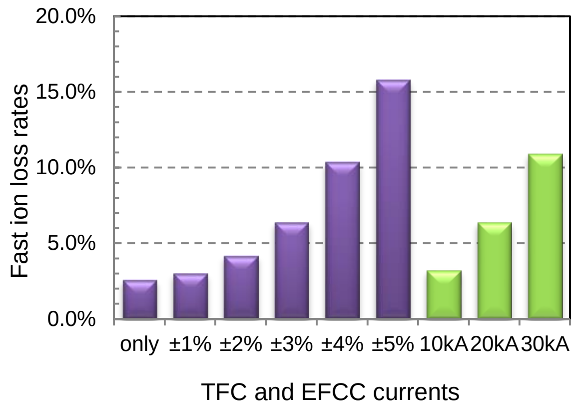

Fig.3 Comparison of fast ion loss rates for TFC distributed currents of 0, ±1, ±2, ±3, ±4 and ±5% cases and EFCC currents of 10, 20 and 30kA cases.

5. Summary

We have proposed a new method to produce RMPs by using toroidal field coils (TFCs) where coil currents are periodically distributed to stochastize edge magnetic field structure. The distributed current of ±1% can produce $B_r \geq$ 5mT. Namely, it is found that a few percent of the increase-decrease rate of TFC distributed currents can produce stochastic structure at the pedestal region. The stochastic structure can affect the fast ions deposited at edge region. Moreover, the stochastic structure can also make footprints spread [8]. It is advantageous to avoid local heat load to diverter targets. Namely, this method without any additional coils is expected to have merit in the viewpoint of heat load distribution for DEMO.

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