

New concept of edge stochastization by toroidal field modulation

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1. Introduction

Toward ITER and DEMO, the establishment of operation schemes to avoid unacceptable heat load to the plasma facing components is urgent and critical issue. Furthermore, these should be established by using realistic technologies and materials. As for transient heat load, an excessive heat load is expected to be induced by an edge localized mode (ELM) with a large amplitude, that is one of the major concerns for ITER. In order to suppress or mitigate large ELMs, application of resonant magnetic perturbations (RMPs) by using internal or external coils seem to lead to good results in current tokamaks [1–4]. This is thought to be attributed to changing magnetic field structure at edge region, thus, stochastization of the magnetic field line. However, the RMP method by using perturbation coils close to a plasma is technically difficult, in particular, in DEMO, due to limited space inside vacuum vessel and high neutron fluence.

Therefore, we have proposed a new concept of edge stochastization by toroidal field coils (TFCs) with toroidally periodic coil currents, hereafter called, "toroidal field modulation (TFM)." Here, the modulation means not temporary but spatially as shown in Fig. 1. In this paper, we report the detail of the new concept of the TFM including magnetic structure, plasma response and fast ion confinement.

2. Magnetic field of TFM

Based on this new concept, we have conducted magnetic field calculations, assuming the ITER-like equilibrium planed in JT-60SA [5]. Figure 2 shows $n = 3$ mag-

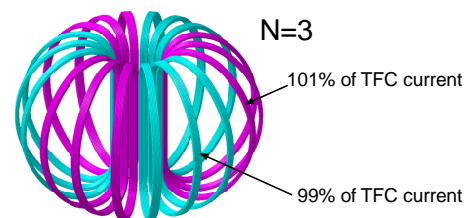


Fig 1. Schematic drawing of TFM 1% modulation degree.

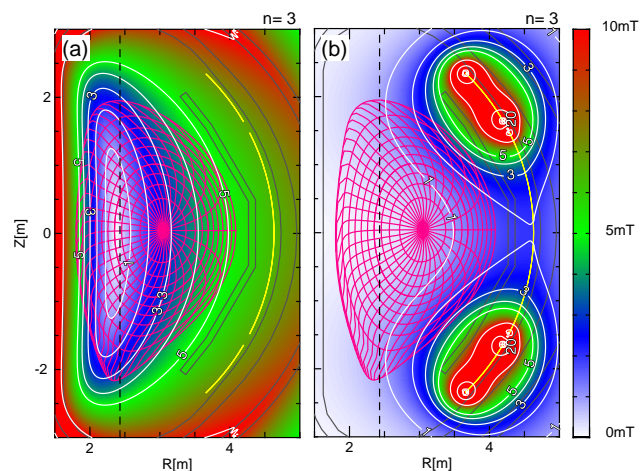


Fig 2. $n=3$ magnetic field patterns ($|\mathbf{B}_r + \mathbf{B}_z|$) of (a) TFM 1% and (b) EFCC 10kA.

netic field patterns by the TFM with 1% modulation degree and the EFCC with 10kA turn coil current. Here, n is the toroidal mode number and the EFCC is error field correction coil planed in JT-60SA that is utilized to produce RMP for ELM control [6]. Magnetic field pattern of TFM, that is similar to the shape of TFC, extends whole region, while that of the EFCC only affect a region near the EFCC.

In order to evaluate how much the RMPs from the TFM 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 3 shows Poincaré

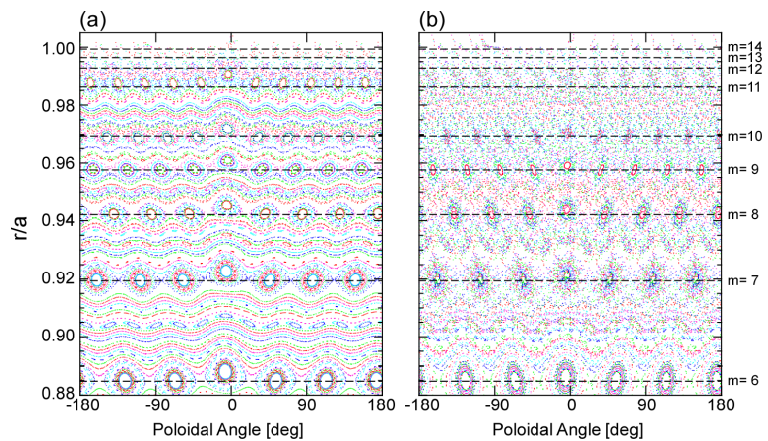


Fig 3. Poincaré plots in TFM 1% and EFCC 10kA cases.

plots of magnetic field lines with the TFM 1% and the EFCC 10kA cases. In the both cases, stochastic region appears at the plasma edge, where $\rho > 0.99$ by the TFM and $\rho > 0.95$ by the EFCC, due to overlapping of neighboring magnetic islands. Here, ρ is a normalized minor radius. Since the assumed pressure profile has a pedestal structure around $\rho \geq 0.97$, the stochastic region by the EFCC 10kA can cover the pedestal region. Thus, the RMP by the EFCC is much effective than that by the TFM, although both cases have almost the same amplitudes of about 5mT at the edge. This difference comes from the dominant poloidal mode components (m) of the magnetic field at the edge. In the TFM case, the non-resonant components of $m = 0, \pm 2$ are dominant. To affect whole pedestal region as wide as the EFCC 10kA, the TFM needs 3% modulation degrees. Although the TFM is less effective than the EFCC, a few percent of the modulation degrees of TFM can produce stochastic structure at the pedestal region.

3. Magnetic field with plasma response

It is found that a few percent of TFM can produce the stochastic structure in the vacuum calculation. However, recent theoretical studies and experimental results [7] show that an externally applied magnetic perturbation could be modified by plasma response. Thus, shielding or amplification of RMP occurs inside a plasma. To evaluate the plasma response with respect to the RMP by the TFM, we have used HINT code, which is a nonlinear 3D MHD equilibrium without the assumption of nested flux surfaces [8], and compared with the results of the vacuum

approximation. The plasma response to the RMP by the EFCC in JT-60SA has been calculated and discussed [9].

Figure 4 shows $n = 3$ magnetic field pattern and Poincaré plot in the case of TFM 1% calculated by HINT code. The plasma response modifies magnetic field in the whole region and enhances stochasticity at $\rho \geq 0.96$, covering the pedestal region. These re-

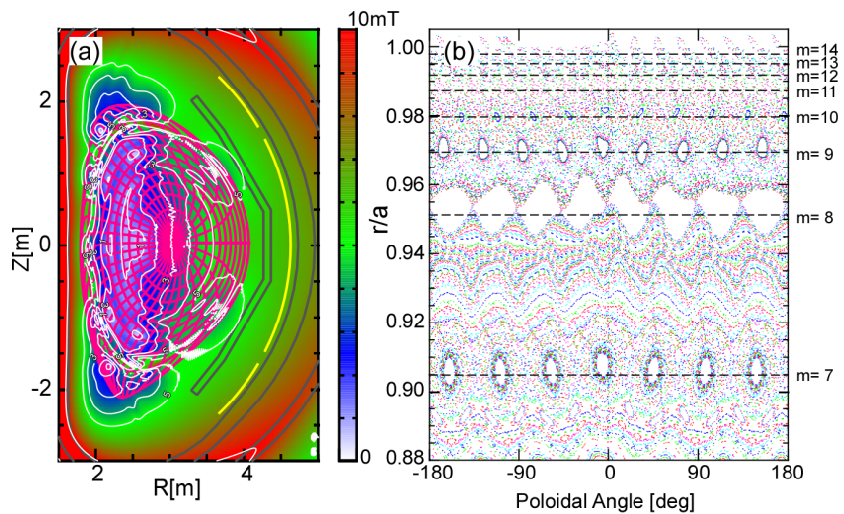


Fig 4. (a) $n = 3$ magnetic field pattern and (b) Poincaré plot in TFM 1% case with plasma response.

sults indicate that the plasma response can help edge stochastization.

Moreover, the TFM can change the magnetic structure in the divertor region as with the EFCC. The footprint pattern on the divertor target by the TFM spreads compared without the TFM. Also, the plasma response increasingly spreads out the wetted area. Since it is advantageous to disperse local heat load on the divertor target, that is, the ergodic divertor (ED) concept [10].

4. Fast ion behavior

Since a fast ion orbit is sensitive to magnetic structure, we have calculated orbits of fast ion from the neutral beam injectors (NBIs) by OFMC [11], taking into account 3D magnetic fields by the TFM and by the EFCC. The total loss of fast ions without the TFM is about 2.6% for the positive ion based NBIs with beam energy of 85 keV. As increasing the TFM modulation degree, the total loss also increases as the square of the TFM as shown in Fig. 5. These lost fast ions

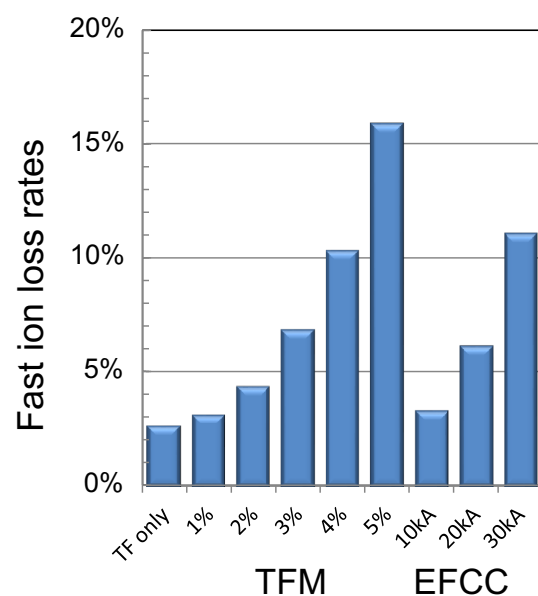


Fig 5. Total loss of fast ions by TFM and EFCC.

are born in the edge region where the RMP applied by the TFM and the EFCC. The dependence of the total fast ion loss on the TFM modulation degree is similar to that of the EFCC current.

6. Summary

We have proposed a new concept of edge stochastization by toroidal field coils (TFCs) with toroidally periodic coil currents, "toroidal field modulation (TFM)." The TFM 1% can produce about 5 mT around the edge region, that is comparable to magnetic fields by the EFCC 10 kA. Since the dominant components of the TFM are non-resonant components such as $m = 0, \pm 2$, the RMP effect is less than the EFCC 10 kA. However, a few percent of the modulation degree of the TFM can produce stochastic structure at the pedestal region. If the plasma response is taken into account, the TFM 1% is enough to produce stochastic region, covering the whole pedestal region. The stochastic structure produced by the TFM can also affect the orbits of the fast ions deposited at edge region. Moreover, the TFM can change magnetic structure in the divertor region so as to spread the foot prints on the divertor targets. It is advantageous to disperse local heat load to divertor targets. Namely, the method of "TFM", that does not need any additional coils, is expected to have merit in the viewpoint of heat load distribution for DEMO.

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