6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Nonlinear MHD modeling on RMP-induced pump-out in KSTAR with realistic tokamak geometry

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One of the most effective methods to control ELMs is to apply resonant magnetic perturbations (RMPs) using 3D coils [1]. Applying RMP leads to a substantial reduction of density pedestal called pump-out, considered necessary for accessing the ELM-suppression state [2]. Recently, nonlinear cylindrical modeling has resolved bifurcative two-tiered pump-outs for the first time [3]. It successfully explained two pump-outs with polarization effect and island penetration physics but left a question about the toroidal effect on the RMP-induced particle transport. This work introduces nonlinear 3D MHD simulations and validations with realistic geometry that reveal a hybrid particle-MHD transport as a key process for driving the bifurcating dynamics in particle transport under RMPs in KSTAR tokamak. Here, nonlinear 3D MHD code JOREK [4,5] and PENTRC [6] codes are coupled for the pump-out modeling. It turns out that the threshold characteristics of pump-out originate from resonant field penetration and island opening [7], showing a good agreement with the previous modeling [8,9].

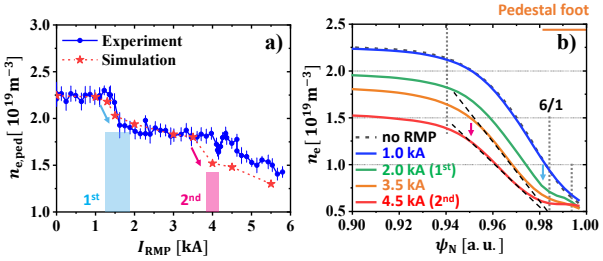

Figure 1. Pump-out simulation results: (a) Height of electron density pedestal ($n_{e,ped}$) versus RMP coil current (I_{RMP}), and (b) evolution of density pedestal profile by increasing the RMP coil current (I_{RMP}). Two-tiered 1st and 2nd pump-outs are marked as blue and red colors in a).

However, the difference is found in the transport processes during the first pump-out in that the polarization effect may be insufficient to explain it fully. Here, pump-outs are attributable to both polarization and neoclassical toroidal viscosity (NTV) [10] effects, showing that the first pump-out observed in KSTAR experiments is reproduced only with these integrated transports. Such an additional process is mainly due to the toroidal effect, which reduces the polarization effect while driving NTV particle transport.

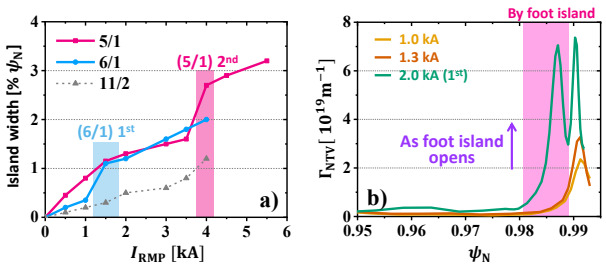

Figure 2. (a) Width of the magnetic island at 5/1 (pedestal top) and 6/1 (foot) rational surfaces versus RMP coil current (I_{RMP}). (b) Evolution of NTV particle flux profile (Γ_{NTV}). Two-tiered 1st and 2nd pump-outs are marked as blue and red colors in a). The location of the 6/1 (foot) island is marked as red color in b).

In addition, the toroidal mode interaction between RMP-induced modes is found to be possible to drive the island opening at the pedestal top, further addressing the importance toroidal effect. This mode coupling suggests a new possible mechanism for second pump-out, which can be correlated to the access condition for ELM suppression.

This material was supported by the U.S. Department of Energy under Awards DE-SC0020372 & DE-AC52-07NA27344. This research was also supported by KFE Kairos and the R&D Program of "KSTAR Experimental Collaboration and Fusion Plasma Research (EN2021-12)" through the Korea Institute of Fusion Energy (KFE), funded by Government funds. Part of this work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training program 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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