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Data-driven prediction and control of radiative collapse in stellarator-heliotron plasmas

Tatsuya Yokoyama[1,2], Hiroshi Yamada[1], Suguru Masuzaki[3,4,5], Byron J. Peterson[3,4],
Ryuichi Sakamoto[3,4], Motoshi Goto[3,4], Tetsutaro Oishi[3,4], Gakushi Kawamura[3,4],
Masahiro Kobayashi[3,4], Toru Ii Tsujimura[3], Yoshinori Mizuno[3], Junichi Miyazawa[3,4],
Kiyofumi Mukai[3,4], Naoki Tamura[3,4], Gen Motojima[3,4], Katsumi Ida[3,4]
[1] Graduate School of Frontier Sciences, The University of Tokyo, [2] JSPS Research Fellow,
[3] NIFS, NINS, [4] SOKENDAI, [5] Kyushu University,
e-mail (speaker): yokoyama.tatsuya17@ae.k.u-tokyo.ac.jp

Prediction and avoidance of radiative collapse in Large Helical Device (LHD) has been investigated with machine learning and sparse modeling techniques. The likelihood of the occurrence of the radiative collapse has been quantified with features of radiative collapse extracted by the sparse modeling technique. The predictor model has been successfully applied to LHD experiment to avoid radiative collapse. Furthermore, the underlying physics of the radiative collapse has been discussed based on the extracted features.

In stellarator-heliotron plasma, radiative collapse is the main issue to limit the operational density. The Sudo scaling is the best-known scaling law of density limit, which suggests that the balance between heating power and radiative power loss is a key together with robust confinement capabilities such as plasma volume and magnetic field[1]. However, the contribution of other operational parameters such as impurity contamination and wall conditions are hidden behind the expression of the Sudo scaling.

In the present study, the feature of the radiative collapse has been extracted by exhaustive search, which is one of the sparse modeling techniques, from the high-density experiment data in LHD[2]. As a result, a combination of parameters that consists of electron density, CIV and OV line emissions, and electron temperature at the last closed flux surface (LCFS) has been extracted as key features of radiative collapse.

The extracted features have been used to quantify the possibility of the occurrence of the radiative collapse, which is called “collapse likelihood”. Based on the collapse likelihood, a collapse avoidance control system has been developed and applied to density ramp-up experiments in LHD. Figure 1 shows the result of the density ramp-up experiments with and without this control. In the discharge without control, radiative collapse occurred in the early phase of the density ramp-up at around 3.6 s. When the control system was employed, the radiative collapse in the early phase was avoided successfully by turning the gas puff off and boosting electron cyclotron heating (ECH). In the latter part of this discharge, the radiative collapse has been avoided only by turning on/off the gas puff and $\bar{n}_e$ was developed up to $1.2 \times 10^{20}\ \mathrm{m}^{-3}$.

Moreover, the underlying physics of the radiative collapse has been discussed based on the extracted features. In this discussion, the EMC3-EIRENE code[3] has been employed to investigate the behaviors of plasma and light impurities in the plasma edge region. Comparing the plasma states before and after the change of the collapse likelihood, the increase of the radiation power by carbon ion seems to be caused by both the change of edge electron temperature and density, and the local accumulation of carbon ions.

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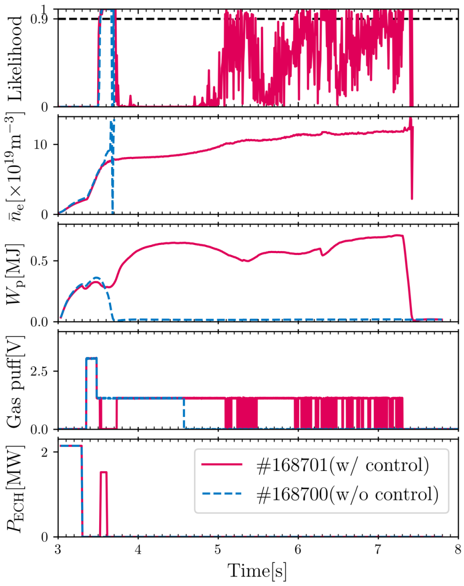

Fig.1 The discharges with and without collapse avoidance control in hydrogen plasma, shown by red and blue lines, respectively.

References

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