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Characterization of transition to detachment of magnetic confinement plasmas via data-driven approach

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This study aims to clarify the occurrence conditions of detached plasma in the Large Helical Device (LHD). and performs state classification and feature parameters extraction by using machine learning. Transition between detachment and attachment is defined as a problem of binary classification.

Reduction of excessive heat load to the divertor is a critical issue in the development of magnetic confinement fusion reactors. For this reason, so-called detached plasma operation is inevitable where the edge plasma does not contact directly the divertor plate. LHD has succeeded in realizing a stable detached plasma by applying resonant magnetic perturbation (RMP) field [1]. The m/n =1/1 magnetic island generated at the plasma edge regulates radiation which secures detached plasma with preventing radiation collapse. Identification of what plasma parameters contribute to the occurrence of detached plasma is expected to lead to the establishment of stable detached operation control and understanding of the underlying physics.

In this study, Support Vector Machine (SVM) and Exhaustive Search (ES) were used as a data-driven approach. A linear support vector machine (SVM) was used as a binary classifier, and data from experiments were used for training and evaluation. Since the phases of attachment/ detachment can be identified clearly by the ion saturation current onto the divertor plate I_{sat} as well as electron temperature at the plasma edge $T_{e,edge}$, the phase is labelled by the level of I_{sat}. Exhaustive search (ES) was used to extract feature parameters to describe the condition of detached plasma from 14 parameters such as line averaged electron density $\bar{n}_e$, magnetic field strength B, radiation power fraction $P_{\mathrm{rad}}/P_{\mathrm{input}}$, beta β, impurity line emissions, m/n = 1/1 resonant perturbed magnetic flux $\Delta\Phi_{\mathrm{eff}}$, and the RMP coil current, etc. excluding two decisive parameters of I_{sat} and $T_{e,edge}$. ES is a sparse modeling technique in which all possible combinations of parameters are evaluated and compared each other [2]. The data set has been extended from the previous one and the analysis has been revisited. In particular, the CIII signal, which was thought to play a major role in detachment, was not included in the parameters in the previous analysis.

As a result of the ES-SVM analysis, the following 3 parameters were extracted: $\bar{n}_e$, B, and $\Delta\Phi_{\mathrm{eff}}$. As shown in Fig.1, attachment and detachment can be classified according to the combination of $\Delta\Phi_{\mathrm{eff}}$, which is an indicator of the magnetic island width actually generated, and other parameters. On the other hand, the RMP coil current, which was considered to be important for detached plasma operation, was not chosen. This is because the width of the magnetic island generated by the response of the plasma is important for detachment, not by the externally applied RMP alone.

Since the present ES-SVM analysis does not take care of temporal changes, the result indicates correlation but not causality. Therefore, the pre- and post-relationships of each parameter in time are also discussed towards causality of the detachment transition with the anomaly detection by the singular value decomposition of waveforms. Here, it is found that CIII, CIV, and $P_{\mathrm{rad}}/P_{\mathrm{input}}$ change before the detachment transition, while $\Delta\Phi_{\mathrm{eff}}$ occurs at a timing close to the detachment transition.

Effect of Ne puff, which facilitates detachment, is also discussed in order to examine the extrapolation and redundancy of the model.

References

[1] M.Kobayashi et al., Nucl. Fusion 53, 093032 (2013).
[2] Y.Igarashi et al., J.Phys: Conference Series 1036, 012001 (2018)

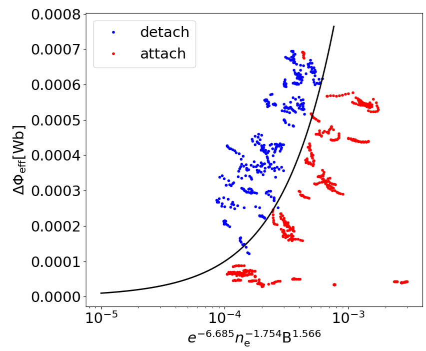

Figure1 Distribution of attachment (red) and detachment (blue) data based on the equation of classification boundary.