22P03

核融合プラズマの非接触化条件に関するデータ駆動型研究
Data-driven study on occurrence condition of detached fusion plasmas

磯部有吾[1]，山田弘司[1]，横山達也[2]，小林政弘[3]，成嶋吉朗[3]，武村勇輝[3]

ISOBE Yugo[1], YAMADA Hiroshi[1], YOKOYAMA Tatsuya[2], KOBAYASHI Masahiro[3], NARUSHIMA Yoshiro[3], TAKEMURA Yuki[3]

東大[1]，量研[2]，核融合研[3]

Univ. Tokyo[1], QST[2], NIFS[3]

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.

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 13 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 $\Delta\Phi_{eff}$, and the RMP coil current, etc. excluding two decisive parameters of I_{sat} and $T_{e,edge}$. The ES is a sparse modeling technique in which all possible combinations of parameters are evaluated and compared each other [2].

As a result of the ES-SVM analysis, the following 5 parameters were extracted: $\bar{n}_e, B$, $P_{\mathrm{rad}}/P_{\mathrm{input}}$, line emission of oxygen (OVI), and $\Delta\Phi_{eff}$. The equation for the classification boundary between attachment and detachment states is given by

$$e^{21.61}\bar{n}_e \mathrm{B}^{-4.37}\left(\frac{P_{\mathrm{rad}}}{P_{\mathrm{input}}}\right)^{4.56} \mathrm{OVI}^{-1.44}\Delta\Phi_{\mathrm{eff}}^{2.42} = 1 \qquad (1)$$

As shown in Fig.1, attachment and detachment can be classified according to the combination of $\Delta\Phi_{eff}$, which is an indicator of the magnetic island width actually generated, and other parameters. On the other hand, the RMP coil current itself was not chosen. This is because the width of the magnetic island generated by the response of the plasma is important for detachment, not only by the externally applied RMP. It should be also noted that the classification of attachment and detachment cannot be made only by $\Delta\Phi_{eff}$, but by the combination with other parameters, which suggests that the five parameters contribute to detachment linked together.

The pre- and post-relationships of each parameter in time are also discussed towards causality the detached transition from the viewpoint of anomaly detection by singular value decomposition (see Fig.2).

This work is supported by the JSPS KAKENHI Grant Number 19H05498 and the National Institute for Fusion Science Grant administrative budgets NIFS22KIPP013.

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

Figure1

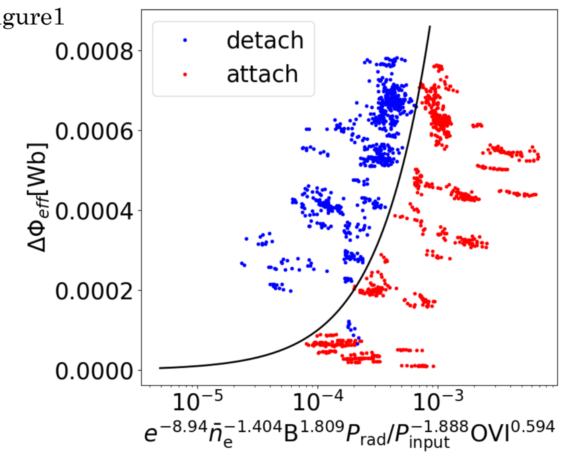

Figure2

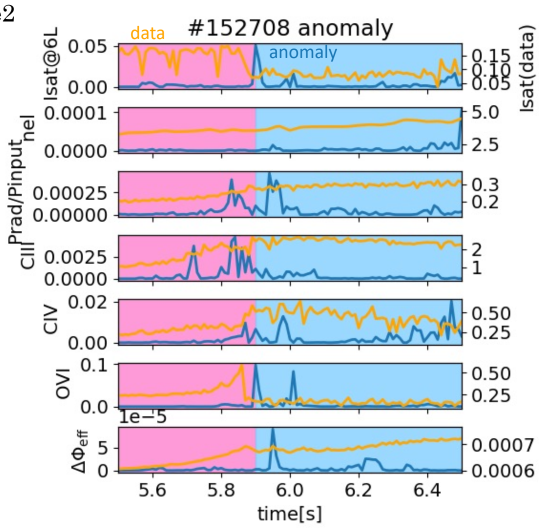

Figure1 Data distribution and classification boundary based on Eq.(1). Red is attachment data and blue is detachment data.
Figure2 Temporal change in anomaly of featured parameters.