

Data-drive Study on Occurrence Condition of Detached Plasma in Large Helical Device

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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. The expression of boundary between these two phases by operational/observable physical parameters has been obtained by data driven approach.

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.

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_{rad}/P_{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 $T_{e,edge}$. In the present study, the dataset is taken logarithms and min-max normalized before training the model so as to get the expression in a power law. ES is a sparse modeling technique in which all possible combinations of parameters are evaluated and compared each other [2]. To avoid overfitting to the training data, 10-fold cross validation was performed to evaluate each combination by generalization performance.

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

the classification boundary between attachment and detachment states is given by

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

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, 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 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 (\bar{n}_e , B , P_{rad}/P_{input} , line emission of oxygen (OVI), $\Delta\Phi_{eff}$) contribute to detachment linked together.

In the presentation, the initial results of the pre- and post-relationships of each parameter in time towards the detached transition are also discussed from the viewpoint of anomaly detection by singular value decomposition.

References

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

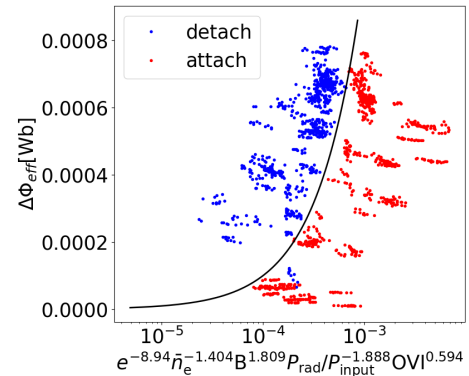


Figure1 Distribution of attachment (red) and detachment (blue) data based on the equation of classification boundary.