Characterization and sparse modeling of radiation collapse and density limit in LHD


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Abstract

- Likelihood of occurrence of radiative collapse has been estimated in Large Helical Device (LHD) by machine learning techniques.
- The likelihood has been estimated with four feature parameters selected by sparse modeling: \( n_e \), CIV, OV, and \( T_{\rho \parallel < 0} \).
- Radiation collapse avoidance control system has been developed based on the collapse likelihood.
- Radiative collapse has been avoided in high-density hydrogen plasma by the control system successfully.

Background

Prediction and avoidance of radiative collapse

- Radiative collapse is one of the major cause of plasma termination in stellarator-heliotron plasma and limits plasma density.
- Prediction and avoidance of radiative collapse are important to improve operational density limit.[10]

Purpose of this study

- Development of the predictor of radiative collapse
  - Classify “close-to-collapse” state and “stable” state by support vector machine (SVM), which is one of machine learning models.
  - The classifier model is trained based on high-density experiment data in LHD.
- Optimization of the input plasma parameters by sparse modeling[27]
  - Development of a control system to avoid radiative collapse
  - The control system is applied to the LHD experiment.

Method

Training SVM classifier

- SVM has been used as binary classifier.
- Dataset has been constructed based on high-density experiment in LHD.
- Gas-puff fueling and NBI heating has been used in these experiments.
- The data has been labeled as either “stable” or “close-to-collapse”.

Pre-processing of training:

- Taking logarithms of dataset
- Min-max normalization

Quantification of collapse likelihood

- Feature of radiative collapse has been extracted by sparse modeling
  - Sparse modeling enables us to extract information from high-dimensional data by taking advantage of the inherent sparseness.
  - Extracted parameters: \( n_e \), CIV, OV, and \( T_{\rho \parallel < 0} \).
- Collapse likelihood has been quantified as the distance from boundary between “stable” or “close-to-collapse” classes.

Collapse avoidance in LHD

Validation of predictor model based on collapse likelihood[28]

- The predictor model has been validated with 535 discharges in LHD other than included in the dataset.
- In about 85% of collapse discharges, collapses have been predicted over 30 ms before they occur.
- False alarms are 5-10% of stable discharges.

Collapse avoidance control system

- A real-time control system to avoid radiative collapse has been developed based on the predictor model.
- When the likelihood exceeds threshold, gas puff is turned off and/or the electron cyclotron resonance heating (ECRH)[29] is turned on.
- A single board computer (Raspberry Pi) calculates has been used to calculate the collapse likelihood in real-time.
- For real-time control, \( T_{\rho \parallel < 0} \) has been replaced by \( T_{\rho \parallel} \), measured by electron cyclotron emission (ECE) measurement.

Conclusion

- The result of data-driven approach to radiative collapse has been applied to plasma experiment in LHD.
- Radiative collapse was successfully avoided by the control system.
- The likelihood will be updated with data in helium discharges.
- Understanding of physical background of radiative collapse based on the likelihood is in progress[31].

Acknowledgements

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References


Expression

<table>
<thead>
<tr>
<th>Parameter used in the dataset</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>( n_e )</td>
<td>Little averaged electron density</td>
</tr>
<tr>
<td>( B_\rho / (D - nF) )</td>
<td>Toroidal magnetic field at axis</td>
</tr>
<tr>
<td>( D \oplus \delta n )</td>
<td>Ratio of ( D ) ions to the sum of ( H ) and ( D ) ions</td>
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<tr>
<td>( I_{\nu e} )</td>
<td>Absorbed input power</td>
</tr>
<tr>
<td>( P_{\nu e} / P_{\nu e} )</td>
<td>Normalized radiation power</td>
</tr>
<tr>
<td>( \delta \omega )</td>
<td>Beta estimated from damaged energy</td>
</tr>
<tr>
<td>( \Delta \omega ), ( \psi_0 )</td>
<td>Plasma shape parameters</td>
</tr>
<tr>
<td>CIII, CIV, OV, OVI, FeXVI</td>
<td>Impurity line intensity normalized by ( n_e ), ( I_{\nu e} ), ion saturation current</td>
</tr>
<tr>
<td>( T_{\rho \parallel &lt; 0} )</td>
<td>Plasma electron temperature at LCFS at vacuum</td>
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References