A Preliminary Investigation into the Prediction of Tearing Mode Evolution Using Deep Learning

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Tearing mode (TM) instability is a major factor affecting plasma performance, and its effective control is critical to the safe and stable operation of fusion reactors[1]. Reinforcement learning has been explored as a means of developing real-time control strategies for mode suppression in recent resarch[2]. These developments collectively highlight that accurate prediction of the evolution of tearing modes is a prerequisite and key to achieving effective suppression.

This study proposes a method to predict rich sequential information of tearing modes in a single step, The prediction is based on future plasma control inputs, resonant magnetic perturbation (RMP) fields, Electron Cyclotron Resonance Heating signals, and historical diagnostic data. The research tasks include the following two aspects:

(1) Binary classification task: Determining whether a tearing mode will occur and identifying the most critical mode component affecting stability — the 2/1 mode.

(2) Regression task: Estimating the frequency and amplitude of the 2/1 mode.

Although recent publications have proposed similar evolution prediction models, they are limited to predicting only the amplitude of the n=1 mode. In contrast, this work presents a more comprehensive approach. We have developed a tearing mode extraction tool, which has been open-sourced on GitHub. The tool takes as input one poloidal and one toroidal ring of magnetic probes, along with measurements of plasma current and toroidal magnetic field strength. It automatically detects the presence of tearing modes and extracts key characteristics such as mode numbers, amplitudes, and frequencies, while also providing visualizations of the extraction results.

The feature extraction algorithm integrates multiple techniques, including cross-power spectral analysis, even--odd mode decomposition, and Fourier decomposition, enabling it to identify tearing modes even in the presence of mode coupling or non-uniform magnetic probe distributions.

The temporal prediction model adopts a CNN+inverted Transformer architecture, as shown in Figure 1. First, convolutional neural networks (CNNs) are used to extract spatial features (embedded tokens) from historical diagnostic signals. The inverted Transformer (iTransformer) refers to treating a time-series signal as a single token, which is then fed into an encoder[3]. Future control signals are input into a decoder, which interacts with the encoder outputs through cross-attention mechanisms to learn the relationships between historical diagnostics and future control signals.

This enables accurate prediction of tearing mode evolution, The AUC for predicting the occurrence of a 2/1 tearing mode greater than 2Gs was 0.963. The false positive rate (FPR) was 0.0885, and the true positive rate (TPR) was 0.8997. Additionally, the cosine similarity between the predicted and actual trends for the labels was calculated as 0.83. For the regression task, the relative root mean square error (RMSE) of the predicted amplitude for actual 2/1 tearing modes with amplitudes greater than 2Gs was 0.36, with a cosine similarity of 0.94. The relative RMSE for the frequency prediction was also 0.36, with a cosine similarity of 0.97. This lays the groundwork for further experimental research on tearing mode mitigation.

References

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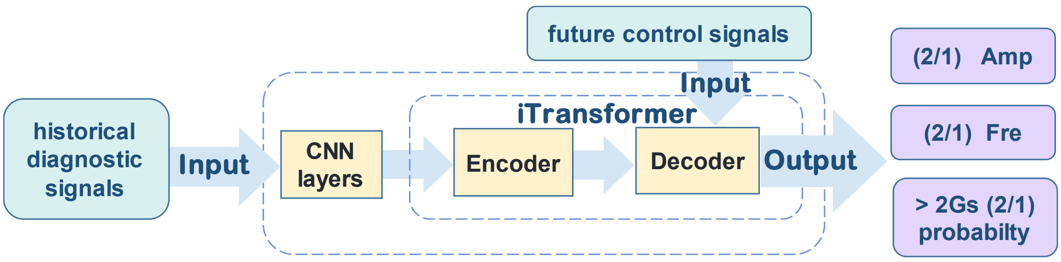

Figure 1 Schematic diagram of the CNN+iTransformer-based model for tearing mode evolution prediction