Machine Learning Based Spectral Fitting and Atomic Physics Corrections for the Main Ion Charge Exchange Recombination Spectroscopy System on DIII-D

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Rapid and accurate neural network (NN) based analysis of the Doppler broadened and shifted Balmer-α spectra from the main ion charge exchange recombination spectroscopy (MICER) diagnostic on DIII-D has been developed to provide the apparent main ion (D+) temperature, rotation, density, and beam emission information from raw spectral data. The temperatures and rotations are typically within 150eV and 10km/s of those obtained from standard least squares fitting approach. The apparent measurements are corrected using a second set of NN models that were trained as a surrogate for the FIDASIM 3D collisional radiative model. FIDASIM provides a comprehensive forward model for the measurement, including a wide variety of atomic physics and spatial smearing effects. At the pedestal top, corrections to the ion temperature are typically 150eV, but can be up to 300eV. The standard deviation of the difference between the surrogate and the full model based correction is <30eV, with some of this difference due to Monte Carlo noise in the FIDASIM model. The training dataset comprises 20,000 FIDASIM simulations spanning the relevant DIII-D parameter space, incorporating varied ion, electron, and impurity profiles, as well as magnetic equilibria. This mapping from real parameters to apparent measurements is inverted during the training of an ensemble of NNs, eliminating a challenging and time-consuming iterative process with a forward model. The complexity of the MICER spectra and associated corrections has limited analysis to high priority shots, despite the wealth of information contained in the spectra. These advances have dramatically reduced the analysis time for single shots from several hours to seconds. The speed-up now allows bulk analysis of thousands of historical shots acquired by the diagnostic during its ~10 yrs of operation on DIII-D, enabling database studies of the main ion properties in the H-mode pedestal. MICER uses 32 channels, covering the core and a high-resolution edge. Its main advantage over standard impurity CER is direct measurement of main ion properties, which differ from impurities, especially in the pedestal region. This application demonstrates how simple machine learning models such as MLPs can provide several orders of magnitude acceleration in the analysis of complex diagnostic data. Details of the historical analysis process will be contrasted against the newer machine learning based approaches along with lessons learned during the development process.

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