Investigation of q-profile and normalized beta control in JT-60SA using reinforcement learning

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Real time control of a safety factor (q) profile and a normalized beta (β_N) has been studied in various tokamaks because they strongly affect the confinement performance and MHD stability of fusion plasmas. In this work, an integrated q profile and β_N control is developed using reinforcement learning. In order to control the q profile and β_N according to the plasma confinement characteristics, a neural network whose input is the state vector $\boldsymbol{s}_i = [t_i, q(\rho, t_i), q(\rho, t_i\text{-}1), T_e(\rho, t_i), \alpha(\rho, t_i), P_{heat}(t_i), P_{heat}(t_{i-1}), \beta_N(t_i), \beta_N(t_{i-1})]$ (α : normalized pressure gradient, P_{heat}: heating power of each actuator) and output is the heating and current drive power $P_{heat}(t_i+1)$ has been constructed and optimized.

The integrated transport code RAPTOR is used since RAPTOR can solve the transport very fast. It has the advantage to do more than one million trials. By randomly changing the parameters which give the thermal diffusivity, plasmas with various confinement characteristics have been simulated and used for training. This parameter randomization allows the neural network to adapt to a wide range of transport characteristics. The neural network has learned to achieve a flat q profile with a minimum value of q_{min} greater than 1, aiming to achieve both high confinement and good MHD stability while β_N is controlled to 2.4.

The trained control system has been verified using another integrated transport code TOPICS. While the heating and current drive profiles of each NBI and ECH beam are prescribed in the training using RAPTOR, the heating and current drive profiles are calculated considering the plasma parameters at each time step in the validation using TOPICS. In addition, CDBM model is used for thermal diffusivity in TOPICS, which is different from the model used in training. With this setup, the applicability of the trained control system to the plasma different from the ones simulated in training has been checked. As a result, it has been confirmed that q profile and β_N can be controlled. This result indicates that the control can be performed even when there is a finite modeling error.