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Identification of multiple eigenmode growth rates towards real-time detection in DIII-D tokamak plasmas

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The successful application of three-dimensional (3D) magnetohydrodynamic (MHD) spectroscopy in the stable DIII-D plasmas enables to directly and efficiently identify the multi-mode eigenvalues in tokamak experiments. The temporal evolution of the multi-mode stability has been successfully detected by offline analysis (figure 1). Moreover, the two eigenmode has been numerically found by running MARS-F code. The eigenmode structures are shown in figure 2.

Generally, the plasma response is modelled by the linear MHD theory, which is consistent with the experimental detection [1, 2]. By analyzing plasma response, one can implement the active detection of the plasma stability. Different from previous works which assume one single dominant stable eigenmode, theoretical study [3] shows the plasma response can contain multiple dominant stable eigenmodes. Thus, a method [4], referred as 3D MHD spectroscopy, has been developed to extract a multi-mode plasma response transfer function. Although this method has been applied in experiments successfully, it takes certain amount of time to extract eigenmodes due to the complicated frequency analysis of signal and nonlinear fitting of transfer function. In order to do the experimental real-time detection, a new method has been developed in this report.

The new method is working directly in the time domain, so it is denoted as TDM. As a counterpart, the previous 3D MHD spectroscopy is denoted as frequency domain method (FDM). The TDM is developed by combining FDM [4] and the subspace system identification theory [5]. The efficiency of the TDM has been proved to be highly potential to implement the real-time detection. The method performs the active detection of stable plasma by utilizing the upper and lower rows of internal current coils to apply well-designed 3D field, and extracting the multi-mode eigenvalues through the subspace system identification of the plasma response measured by 3D-field magnetic sensors distributed at different poloidal locations. The results point to the potential development of an advanced strategy for real-time monitoring the plasma stability based on the extracted eigenvalues of stable modes. The equivalence of TDM with the FDM [4] has been numerically corroborated. This method has the theoretical possibility to detect the stable kink mode and tearing mode, and accordingly real-time monitor its temporal evolution, which can be extremely practicable to predict and avoid the severe disruptions in future fusion reactors.

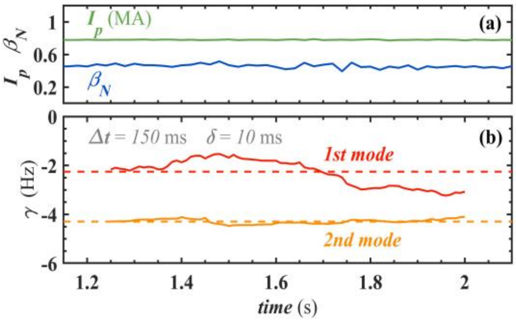

Figure 1. Temporal evolution of the extracted stable eigenmodes accompanying with equilibrium parameters. Here we found 2 dominant stable modes. We use Δt period of time to fit the model, and update data every δ time. In this case, Δt=150ms, δ=10ms. It is noted that δ will depend on calculating time of the fitting process and other operations such as passing data to plasma control system. The time required for calculation of each fit is only a few milliseconds. For the present real-time code, we can insure the Δt and the δ to be less than 100ms and 10ms, respectively.

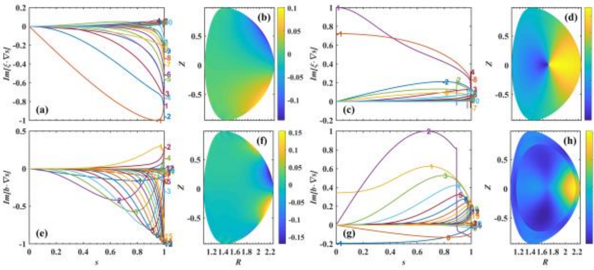

Figure 2. Eigenmode structures of the 1st mode (a)-(d) and the 2nd mode (e)-(h). (a)(b)(e)(f) represent magnetic perturbation. (c)(d)(g)(h) represent perturbed displacement. The first mode has more core structure. While the second mode has the peeling structure with more edge perturbation.

References

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