Equilibrium Analysis of KSTAR H-mode and VEST Reference Scenarios using a Newly Developed Equilibrium Reconstruction Code

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1. Introduction

Plasma equilibrium reconstruction is essential in analysis of tokamak experiments to identify the basic equilibrium parameters. IDK [1] is a newly developed equilibrium reconstruction code dedicated for analyzing KSTAR experiments in which a multi filament representation of plasma is applied to deal with large magnetic uncertainties such as effects of ferromagnetic materials in PF coils and up-down asymmetric fields from cryostats. As a result, it has shown accurate plasma position and shape reconstructions that are well consistent with fast framing camera images in KSTAR.

In KSTAR 2010 campaign, H-mode plasmas were firstly achieved by preprogrammed plasma shape control under marginal auxiliary heating power, so that it showed unusual, abrupt increases of q_{95} and l_i which might be correlated with L-H transitions. The IDK code is updated recently to analyze these effects by extending its capability for profile reconstructions. In this paper, the results are compared with EFIT and the effects of the plasma configuration on the L-H transition at KSTAR are discussed.

In addition, the IDK is also applied for design study of the magnetic diagnostic systems of VEST (Versatile Experimental Spherical Torus) under construction at Seoul National University. Optimal number of magnetic probes for VEST is discussed through IDK reconstructions for various reference equilibriums obtained by the TES code [2].

2. L-H transition in KSTAR 2010 campaign

In KSTAR 2010 experiment, L-H and H-L transitions were activated mostly by plasma shaping. In this regards, analyzing the plasma shape parameters such as elongation, triangularity, position of X-point and limiter-plasma gap distance is important. Most of H-mode experiments, plasma profiles such as q- and current density profiles showed unique responses when plasma is rapidly diverted. Reasonable identification of the plasma profiles is needed to analyze L-H transition but most of profile measurements were not available except equilibrium reconstruction in the campaign. To analyze plasma profiles, IDK is updated to reconstruct the plasma profiles and adopted to KSTAR 2010 H-mode plasmas.

As shown in figure 1, shot #4333 has typical characteristics of 2010 KSTAR H-mode plasmas. Plasma is shaped during current ramp up, and usually pushed away radially. During this process, the plasma touches the outer limiter and strongly scraped off. After the shaping is completed, the plasma changes the configuration from the limited to the diverted shape and the radial position recovers the reference location quickly, the L-H transition was occurred in H-mode shots. And rapid increase of l_i and q_{95} in L-H transition is observed in all H-mode plasmas according to EFIT analyses.

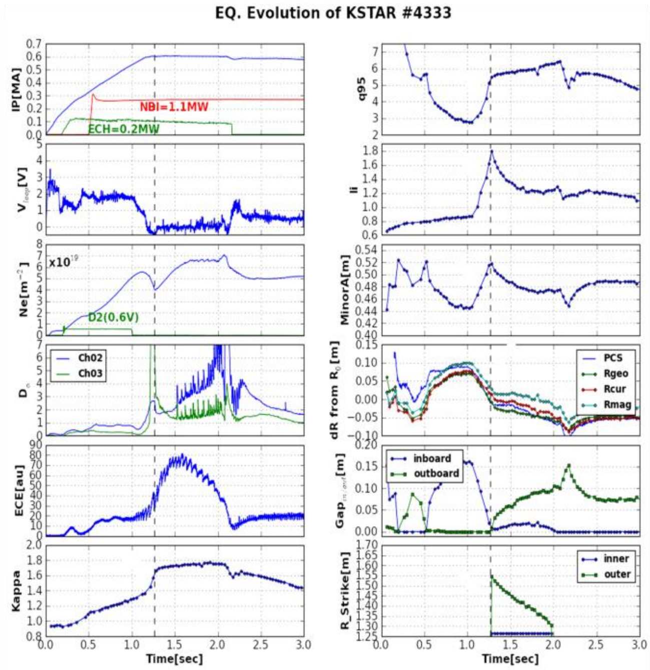

Figure 1 General characteristics of 2010 KSTAR H-mode. L-H transition is occured when shaping is completed and detached from outer limiter.

To analyze the plasma shape parameters and profiles robustly, EFIT and IDK are used and compared each other for an H-mode shot, #4323 as shown in figure 2, black one is IDK and yellow one is TEFIT. Globally, IDK shows better agreement with the experimental data. In terms of poloidal beta, IDK shows better agreement with the diamagnetic loop data rather than EFIT. But with respect to l_i evolutions, both IDK and EFIT show completely different behavior. EFIT says significant changes of l_i during L-H transient, but IDK no significant change. In order to clarify this, delicate profile measurements are needed which are planned for the forthcoming campaign in KSTAR. Abrupt increasement of the D_α signals from the divertor region implies that the plasma touches the divertor plate. Two vertical dot lines shown in figure 2 represent the diverted time estimated

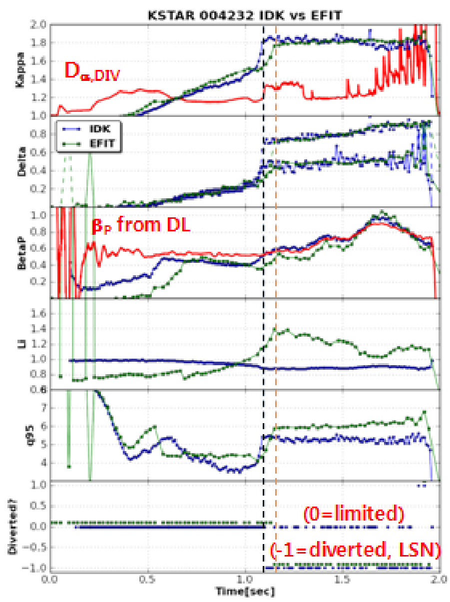

Figure 2 Equilibrium analysis of shot # 4232 using EFIT and IDK

by IDK and EFIT, respectively. Comparing with the experimental D_α signals, EFIT shows about 100 ms delayed diverted time, but IDK shows the well matched result.

3. Evaluation of the magnetic diagnostic system in VEST

In VEST, continuous merging is adopted for plasma current ramp up scenarios to overcome the major weakness of spherical tokamaks, low volt-seconds due to limited cross-sectional area of the central solenoid. In the merging scenario, two small plasmas are generated both upper and lower side of the vacuum chamber and merged in the middle main chamber as presented in figure 3 (a). Therefore, the generated main plasma in the middle chamber is expected to be much smaller than the vacuum chamber and can have various positions. Magnetic diagnostics are installed along the square-shaped vacuum chamber wall, which is different from the configuration of the main plasma, hence optimal positioning of the magnetic diagnostics are needed for reliable equilibrium reconstruction of both the small and the main plasma.

To evaluate the capability of magnetic diagnostics for equilibrium reconstruction, number of the magnetic probe is varied. Magnetic diagnostic system of VEST is composed of 1 in-vessel Rogowski coil, 3 out-vessel Rogowski coils, 15 flux loops, and 16 magnetic probes in the initial phase and 64 in the upgraded phase. Reconstruction capability is evaluated in various plasma conditions using IDK and TEFIT [2], which is an EFIT type algorithm equilibrium reconstruction code.

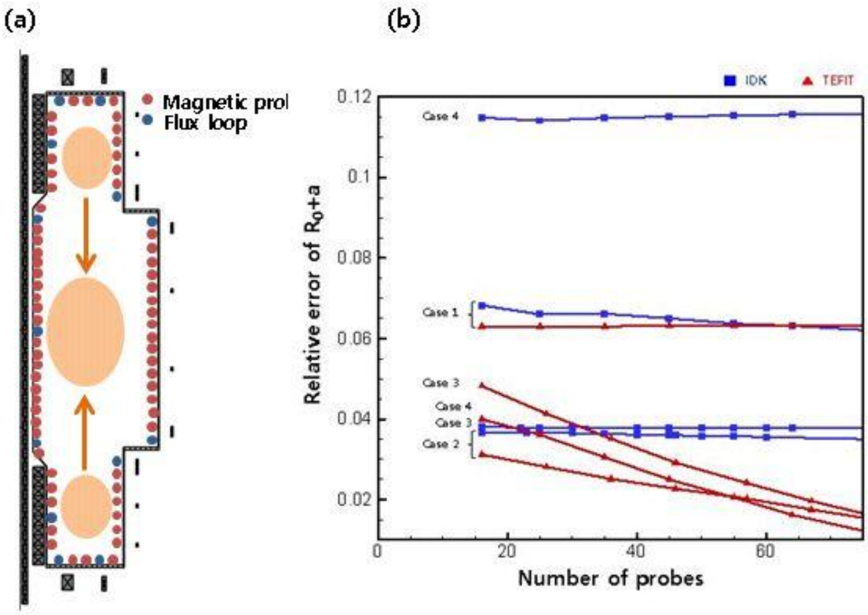

Figure 3 Poloidal cross-section of VEST. Distribution of the magnetic diagnostic system and scheme of the merging scenario (a). Accuracy of the magnetic diagnostic system in various number of magnetic probes in 3 cases (b).

There are no experimental results from VEST yet, reference equilibria are generated by the TES code. A small plasma in the upper chamber (case 1), a main symmetric plasma (case 2), a main plasma located 0.2 m upward (case 3), and a highly elongated main plasma which has the elongation value 1.7 (case 4) are studied and compared with the reconstructed equilibrium results under various number of the magnetic probes. To evaluate the accuracy of the plasma boundary reconstruction, (R_0+a) values are compared.

Accuracy of IDK is highly related to equivalent filament configurations rather than the number of probe as shown in figure 3 (b), comparison between case 2 and case 4. Both cases use circular filament configuration similarly, but accuracy is quite different. As the initial experiments in VEST will be concentrated on generation of the small plasmas like as case 1 for merging scenarios (see figure 3 (b)), TEFIT is expected to exhibit better accuracy than IDK. With respect to the main plasma, accuracy of TEFIT is affected by the number of magnetic probes and gives better results if number of probes is above 35.

4. Summary

A Multi-filament plasma boundary reconstruction code, IDK was upgraded to reconstruct plasma kinetic profiles and applied to 2010 KSTAR H-mode plasmas. As the L-H transition is found to be strongly correlated with the plasma shaping in KSTAR, equilibrium reconstruction capability of IDK is evaluated against EFIT with particular focus upon the gap distance between the plasma and the outer limiter. As a result, IDK shows more accurate results than EFIT globally.

IDK is also used to evaluate the magnetic diagnostic system in VEST. The equilibrium parameters are reconstructed for plasmas with various position and shape by varying the number of magnetic probes. The results are compared with an EFIT type equilibrium reconstruction code, TEFIT.

Reference

[1] Jeon. Y. M., et al., “Equilibrium Reconstruction of KSTAR Plasmas with Large Uncertainty on Magnetics”, Fusion Energy Conference 2010, exs p5-08, (2010)

[2] Jeon. Y. M., et al., Ph.D thesis, (2006)