27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** *(2000) 336 -339*

Simulation Study of KSTAR Target Operating Modes using ASTRA

J.Y. Kim, M.H. Ju, Hogun Jhang, A.R. Polevoi[1] and G.V. Pereverzev[2]

Korea Basic Science Institute, 52 Yeoeun-dong, Yusung-ku, Taejeon, Korea
[1] RRC “Kurchatov Institute”, Moscow, Russia
[2] Max-Planck Institute for Plasma Physics, D-85748 Garching, Germany

Abstract. An integrated discharge simulation code, called ‘Tokamak Simulator’, is being developed for the self-consistent modeling of KSTAR (Korea Superconducting Tokamak Advanced Research) target operating modes, and eventually for finding optimum operation scenarios to realize the long pulse operation of advanced tokamak (AT) modes in KSTAR device. In the first step to develop such a code, we have recently implemented several heating and current drive modules of NBI, ICRH/FWCD, and LHCD, into the ASTRA (Automatic System of TRansport Analysis in a tokamak) transport code. Here, we introduce briefly this integration wok and report some simulation results of KSTAR operating modes obtained using the integrated ASTRA code.

1. Introduction

A main mission of KSTAR (Korea Superconducting Tokamak Advanced Research) device [1] is to explore the steady state operation capability of high-performance AT (Advanced Tokamak) modes. During the conceptual design of KSTAR, several target operating modes, including the AT modes such as the high-beta H-mode and the reversed-shear mode, have been identified and some preliminary simulation studies using TSC (Tokamak Simulation Code) have been performed to check their operational feasibility [2]. For a more self-consistent modeling of the KSTAR target operating modes, we have recently decided to develop an advanced discharge simulation code, which is called ‘Tokamak Simulator’. As shown in Fig. 1, the main concept of tokamak simulator is to integrate the sub-codes or modules from four areas; (i) heating and current drive, (ii) transport and turbulence, (iii) MHD stability, and (iv) edge and divertor, into a main transport code. Note in most current discharge simulations the above areas are being treated separately, or some assumed forms are used to model the areas. Through a more realistic modeling using ‘tokamak simulator’, we expect to find the most optimum scenario and actuator/controller systems to achieve the long-pulse operation of high-performance AT modes in KSTAR.

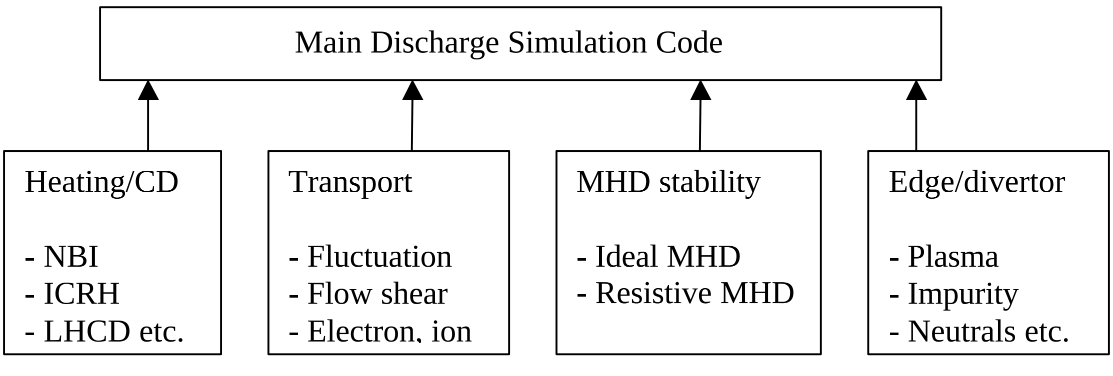

Fig. 1 Conceptual diagram of ‘Tokamak Simulator’

2. Progress in the 'Tokamak Simulator' development

Here, we briefly describe the progress made up to now in the development of 'Tokamak Simulator'. In order to develop an efficient tokamak simulator, we need to first choose a proper main code into which the heating, transport, stability, and edge modules will be integrated. ASTRA (Automatic System of TRansport Analysis in a tokamak) code [3] has been selected as a main code. ASTRA code solves the 1-D fluid transport equations with a fixed boundary equilibrium solver. It is relatively fast and easy to implement various sub-codes or modules to it. An interactive simulation is also possible, so we can monitor simulation results and control parameters in real time during a simulation

In the first step toward the tokamak simulator development, we started to implement the heating and current drive modules to the ASTRA. For NBI part, a module already implemented in ASTRA has been adjusted to the environment of KSTAR NBI system. For ICRH/FWCD part, the full-wave code, TORIC, has been combined to the ASTRA, while the ray tracing code, LSC, has been implemented to model the low hybrid current drive. A time-dependent, self-consistent calculation of the heating and current drive has been performed for some KSTAR target operating modes using the integrated code, and the results will be presented in the next section.

For the development of a useful tokamak simulator, there remains much work to be done. We need to further implement the modules of transport/turbulence, stability, and edge/divertor. It is required to find or develop a fast, but accurate module for each area. In particular, for the transport area it seems to be important to utilize the explicit fluctuation/shear flow evolution equations, rather than a simple empirical formula of transport coefficient. The effort to save computing time, for example, by utilizing the massive-parallel calculation scheme should be also emphasized.

3. Simulation Results and Discussion

As shown in Fig. 2, the KSTAR device is a medium-size, shaped tokamak with R=1.8m, a=0.5m, κ=2.0, δ=0.8. Nominal plasma current and toroidal B-field are I_P=2MA, B_T=3.5T, respectively. KSTAR operation consists mainly of two phases of baseline and upgrade, with the heating power P_{NB}=8MW, P_{ICRH}=6MW, P_{LH}=1.5MW for baseline, and P_{NB}=16MW, P_{ICRH}=12MW, P_{LH}=3MW for upgrade (even though the upgrade power is not finalized yet and some ECH/ECCD power can be added). Corresponding to each phase, several target operating modes have been identified. Here we present a simulation study of the reference high-beta mode and the reverse shear mode in upgrade phase among them. Special emphasis is put on estimating the non-inductive current drive capability of the reference mode, while the reverse-shear profile formation capability of the reverse shear mode. An empirical formula is used for the anomalous thermal transport coefficient, and the density profile evolution is prescribed, for the simplicity.

			Heating & CD Systems	Baseline	Upgrade
Major Radius	R	1.8 m			
Minor Radius	a	0.5 m			
Toroidal Field	B_T	3.5 T	Neutral Beam	8 MW	16 MW
Plasma Current	I_P	2.0 MA	Ion Cyclotron	6 MW	12 MW
Elongation	κ	2.0	Lower Hybrid	1.5 MW	3 MW
Triangularity	δ	0.8			
Field Null		Double null	Pulse length	20 sec	300 sec

Fig. 2 KSTAR major machine parameters

In Fig. 3, we show a typical time-evolution of plasma parameters for the upgrade reference mode. Note the plasma current, shape, input power, and density have been prescribed, while the non-inductive current, q-profile, and temperatures are calculated self-consistently. Also shown are the radial profiles of temperature, q(r), and driven current obtained in quasi-steady state limit. Figure 3 shows that with the input power, 25 MW [16(NBI)+6(FW)+3(LH) in co-direction], the non-inductive current, more than 2MA (I_{NB}=0.91MA, I_{BS}=0.81MA, I_{FW}=0.25MA, I_{LH}=0.50MA), can be driven even at the high plasma density Ne(0)= 1.25 x 10^{20} m^{-3}. Noting the driven current usually increases with lower plasma density, this suggests that there will be a wide range of operation space for the 2MA non-inductive long-pulse scenario with the upgrade power. Figure 3 also shows the radial profile of driven current. The NBI-driven and the bootstrap currents appear to have broad and slightly off-axis profiles, while the FW and the LH driven currents have peaked profiles in the center and near edge region, respectively. Plasma beta value appears to have about β = 3.5 %, (or β_N=3.1) with the input power (when we adjust the transport coefficient such that the confinement time corresponds to H_{93}=1 with τ_E ~115ms).

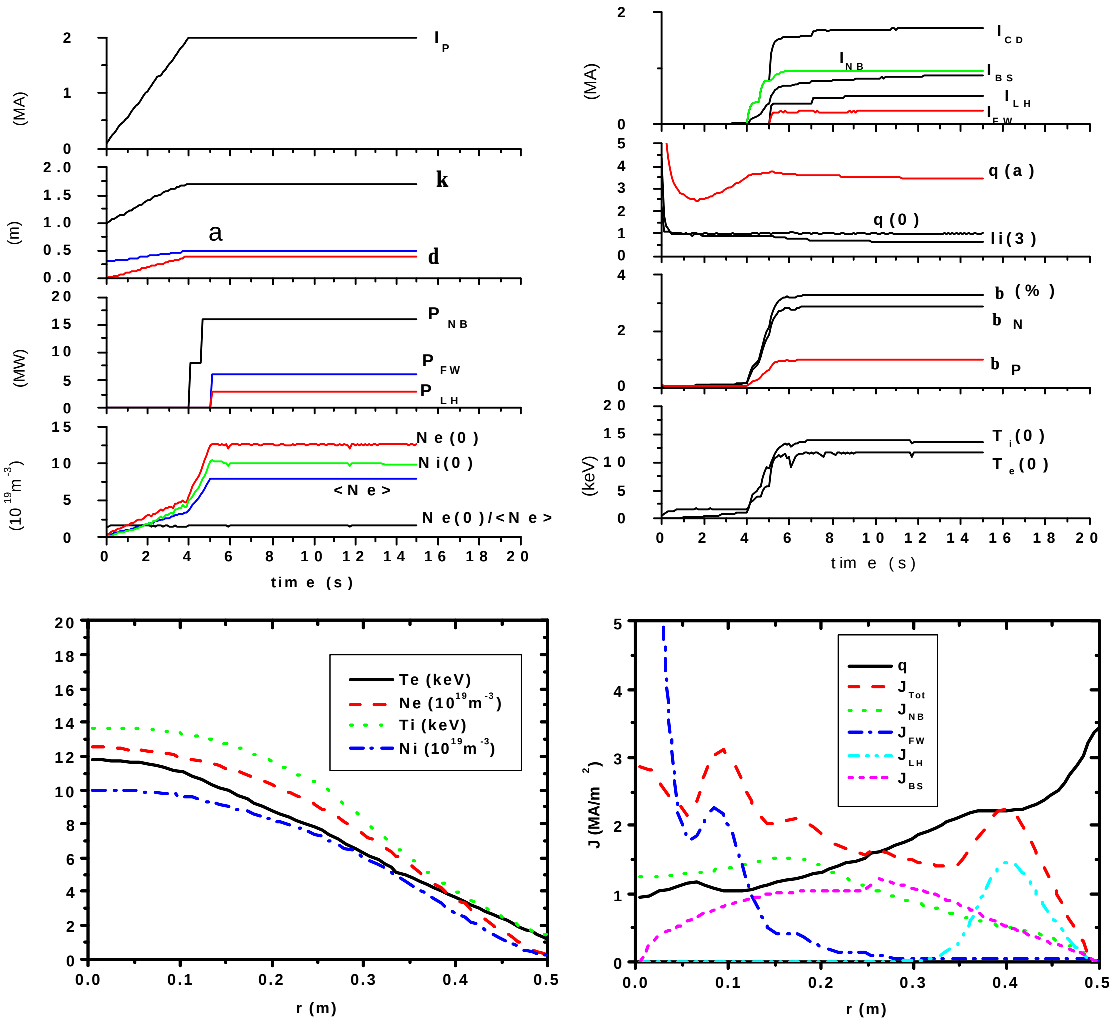

Fig. 3 Time evolution of plasma parameters, and radial profils of temperature and driven current in quasi-steady state limit (t=15s) for the upgrade reference mode.

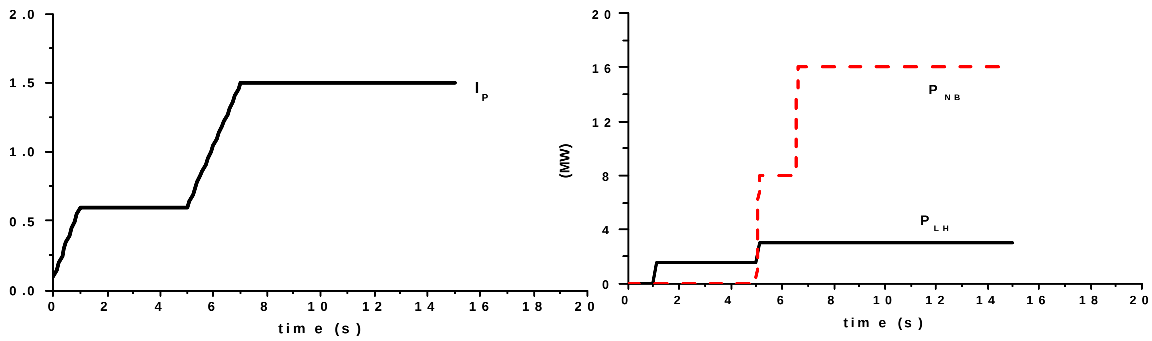

Fig. 4 Plasma current ramp-up and heating scenario for the reverse-shear mode in KSTAR

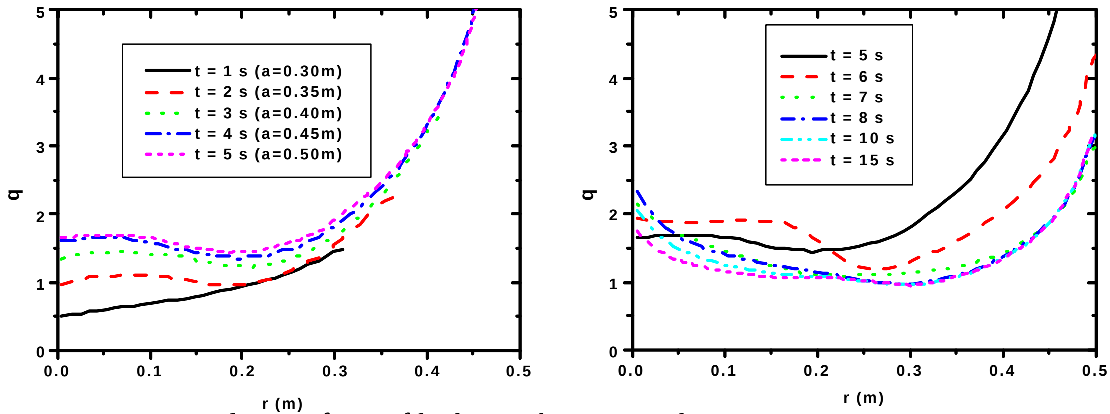

Fig. 5 Time evolution of q-profile during the reverse-shear scenario

Finally, in Figs. 4 and 5, we show the simulation results of the reverse-shear mode. It is noted that the usual fast ramp-up scenario for the reverse-shear profile formation may be not available to KSTAR, mainly because the fast ramp rate can generate a large heat from AC-loss inducing a quench of superconducting PF coils. An alternative scenario, compatible with normal ramp rate, has thus been devised, as shown in Fig. 4. The new scenario is characterized by two-steps current ramp-up and the utilization of LHCD during the first flat-top phase. By applying off-axis LHCD during the first flattop period where the plasma current is small (~ 0.6 MA), we can relatively easily increase q(0) and get a reversed shear profile, as demonstrated in Fig. 5. Once q(0) has become a large value (>1), we take the second ramp-up in the NBI preheating. Due to the high temperature of plasma at this stage, q(0) is almost frozen and the hollow q-profile can be maintained during the second ramp-up period to the full current (here, 1.5MA). From the present self-consistent simulation we find that a flexible real-time control of LHCD spectrum is essential to get a smooth q-profile evolution during the second ramp-up period. Also, a realistic modeling of anomalous transport appears to be critical to simulate the internal transport barrier formation and the bootstrap current alignment, and this-kind work will be carried out in the future.

* Supported by the Korean Ministry of Science and Technology under the KSTAR contract.

[1] G.S. Lee et al., Nucl. Fusion, Vol. **30**, 576 (2000).
[2] KSTAR Physics Validation Review Doc., Korea Basic Science Institute, (1997).
[3] G.V. Pereverzev et al., IPP Report 5/42, Max-Planck Institute, (1991).