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Transport Simulation of The Operation Modes in a KT-2 Tokamak

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Abstract

To develop operation scenarios of KT-2 tokamak, 3 operation modes(OH, high β and high bootstrap) deduced from zero dimensional steady-state power balance are examined with TSC(Tokamak Simulation Code) time-dependent transport code. Plasma profiles are evaluated self consistently during simulations and plasma shapes are maintained by feedback control on PF coil currents. Simulations show operation modes which are typical of KT-2 expected discharges are compatible with the KT-2 PF system design specifications[1].

I. Introduction

KT-2 device concept[1] includes such new physics issues as high bootstrap current, non-inductive current drive, possibility of steady-state tokamak operation, and the second stability regimes, none of which is supported yet by solid experimental evidences. However, the baseline performance and the corresponding operation regimes of the KT-2 tokamak are derived within the framework of existing tokamak design principles such as used in the ITER design[2]. The design principle for the baseline KT-2 tokamak is, in fact, inclusive of all the operation regimes in each of which the KT-2 tokamak is conceptualized, wherever possible.

In this study, 3 operation modes(OH, high β, high bootstrap) which are deduced from zero-dimensional power balanc equation are examined with the TSC transport code[3]. Time-dependent simulation is a powerful tool in predicting performance of new tokamak since it provides self-consistent profiles of densities, temperatures, heating and current drive. TSC evolves MHD equations describing transport time-scale evolution of axisymmetric magnetized tokamak plasma. Plasma profiles are evaluated self consistently and plasma shapes are maintained by feedback control on PF coil currents. MHD stability of KT-2 equilibria is investigated through β, density limit and (ℓ_i-q) diagram during simulation. Compatibility with the KT-2 PF system design specification is investigated through volt-second accounting and PF coil current waveform which is an output from the simulation.

II. KT-2 Performance and the Operation Regime

KT-2 plasma performance is estimated by solving zero dimensional power balance equation. In the thermal equilibrium states during the discharge, plasma heating power is balanced by heat loss through conduction and radiation:

$$P_{con} + P_{rad} = P_{OH} + P_{inj.} \quad . \tag{1}$$

where P_{inj} is the auxilliary heating power, P_{OH} is the ohmic heating power, P_{rad} is the radiation loss consisting of bremsstrahlung and synchrotron radiation, and P_{con} is conduction loss.

For a prediction of the energy confinement time $\tau_{E,}$ the so-called ITER L-mode power scaling[2] is adopted:

$$\tau_E = H_f \, 0.048 I_p^{0.85} R_0^{1.2} a^{0.3} \chi^{0.5} n_{20}^{0.1} B_0^{0.2} A^{0.5} (P_{con} vol)^{-0.5} \tag{2}$$

Confinement improvement possibility represented by recently observed new tokamak discharges such as H mode[4], pellet mode[5], improved L mode[6], and VH mode[7] are incorporated into eq.(2) as the confinement improvement factor H_f.

Figure 1 summaries plasma performance and operating regimes of KT-2 for (a) H_f = 2.0 and (b) 3.0 as function of the heating power. KT-2 machine and plasma parameters used are: A = 5.6, R_o = 1.4 m, B_o = 3.0 T, I_p = 500 kA, α_n = 0.5, α_T = α_j = 1.0. For the H_f = 2.0 case, about 10 MW heating power is required to reach the beta limit. However, this heating power drops to about 5 MW for H_f = 3.0.

To study the bootstrap current effects in FWCD at KT-2, it is necessary to control the plasma current and density, toroidal field, and the aspect ratio accordingly. In Figure 2, the bootstrap current fraction expected for the heating power of 1 MW and 5 MW is indicated as function of q_{95}, i.e., the plasma current when H_f = 3.0 . The bootstrap current fraction increases as the plasma current is lowered and as the toroidal field is lowered. The bootstrap current fraction bigger than 80% will be achievable with 5 MW heating

III. KT-2 Transport Simulation

From Fig. 1, operation modes of KT-2 can be deduced which are typical of KT-2 tokamak discharges ; (1) OH mode, (2) high ß mode, (3) high bootstrap mode. For these modes, TSC time-dependent transport simulations of 3 operation modes are performed to determine the profiles of plasma pressure, density and bootstrap current profiles in the current flattop, and to demonstrate the compatibility with KT-2 PF system design specifications through MHD stability consideration and PF coil current waveform from plasma shape control.

TSC evolves thermodynamic variables with respect to magnetic surface containing a fixed toroidal flux Φ within a constant poloidal flux Ψ surface which is determined by force balance equation, Faraday's Law and Ohm's Law. For details of transport equations, we refer the original paper describing TSC model in Ref. 3.

The main results of simulations are summarized in Table. 1.

Table 1 summary of transport simulation

Parameters	Operation modes	OH	5MW Heating	5MW HiBS
Toroidal field, B_0	**(T)**	**3.0**	**3.0**	**2.0**
Plasma Current	**(kA)**	**500**	**500**	**300**
q_{95}		**2.7**	**2.8**	**3.2**
Average electron density	**($10^{19}m^{-3}$)**	**10.0**	**10.0**	**5.5**
Electron temperature	**(keV)**	**0.5**	**2.0**	**3.3**
$\beta_N=\beta/(I_p/aB_0)$		**0.75**	**2.8**	**3.8**
$\varepsilon\beta_p$		**0.1**	**0.41**	**0.6**
Energy confinement time	**(ms)**	**80**	**60**	**30**
Bootstrap fraction	**(%)**	**10.0**	**45**	**80**
ICRF power	**(MW)**	**-**	**5.0**	**5.0**
ECRH power	**(MW)**	**-**	**1.0**	**1.0**

Throughout simulations, toroidal magnetic field is maintained 3.0 T(2.0 for high bootstrap mode) for the entire simulation and plasma current is ramped from 20 kA at t=0.0 sec to the falttop value of 500 kA(300 kA for high bootstrap mode) at 0.5 sec. The electron density is programmed to increase linearly with time to the flattop value of $<n>=1.0\times10^{20}$ m^{-3} (0.55×10^{20} m^{-3} for high bootstrap mode) with peak to average value of 0.6. The effective charge Z_{eff} is set to 2.0. Auxiliary heating is assumed as $S_{ICRH}(\hat{\Psi}) = \frac{d^2\,(\hat{\Psi})^{a1}(1-\hat{\Psi})^{a2}}{(\hat{\Psi}-a)^2+d^2}$, where $\hat{\Psi}$ is the normalized poloidal flux.

Fig.3 shows snapshots of plasma-vacuum interface at various times during plasma evolution. The plasma is grown from an inboard limited circular plasma at t=0.0 sec, becomes diverted at t~0.4 sec, and reaches a elongation of κ=1.8 and triangularity of δ=0.6 at start of flattop. The plasma shape (minor radius = 25 cm, elongation κ=1.8 and triangularity δ=0.6) is maintained by feedback control on PF coil currents.

A trajectory of KT-2 equilibria in ℓ_i-q space, in which shaded region represents the region of MHD instability, remains stable region during entire current ramp up and flattop period as shown in Fig. 4 for high bootstrap mode which is the most dangerous due to high bootstrap current.

The poloidal flux contour and current profile as a function of toroidal flux are shown in Fig. 5. Bootstrap current is seen to be 80 % of total toroidal plasma current and 90 % when volume average density increases to $8\times10^{19}\ m^{-3}$.

PF coil currents waveforms obtained as an output from simulation are shown to provide the proper fields to maintain the OH, high β, high bootstrap equilibria within it's design specifications.

IV. Summary

Profiles evolution of KT-2 opertaion modes(OH mode, 5 MW heating mode and 5 MW high bootstrap mode) is addressed using TSC time-dependent transport code and performance estimation obtained from zero-dimensional studies are confirmed by transport simulation. Simulations indicate that trajectories of equilibria remain in stable region during entire current ramp up and flattop period and PF system can provide proper equilibria fields for KT-2 operation modes.

V. References

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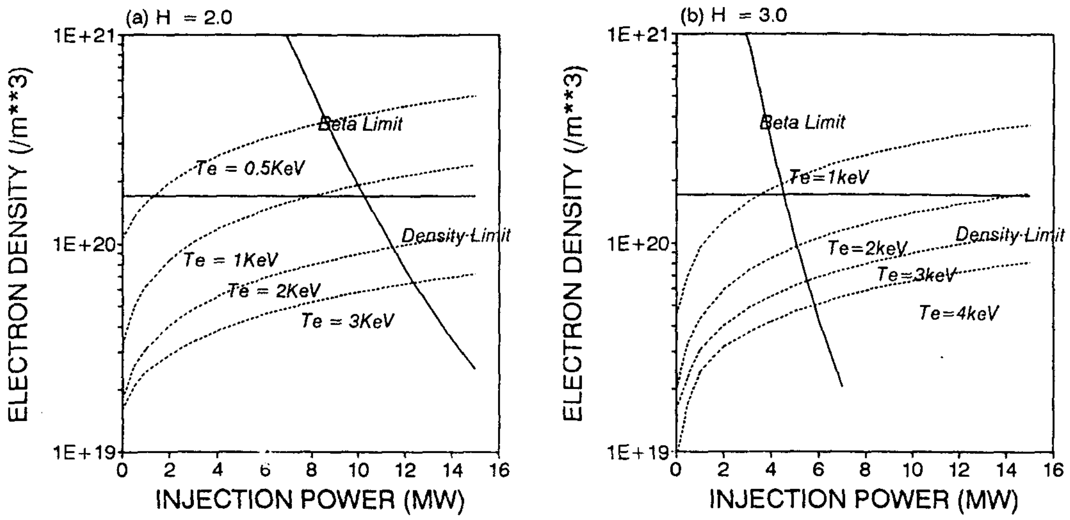

Figure 1. KT-2 operating regimes as function of the heating power. (a) H_f=2.0, (b) H_f=3.0.

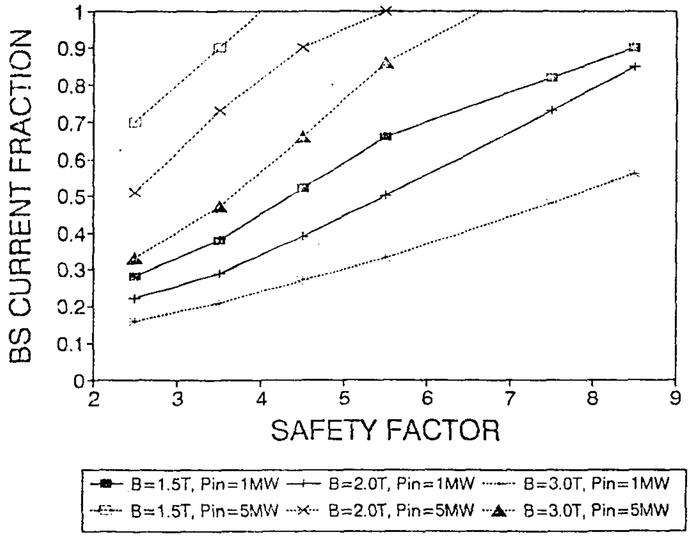

Figure 2 Bootstrap curent fraction as function of the edge safety factor when H_f=3.0

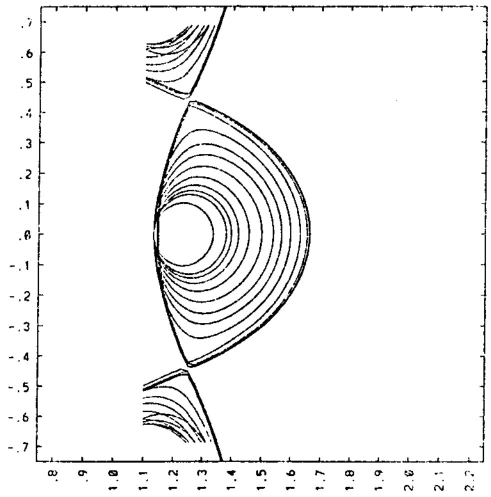

Figure 3 Plasma-vacuum interface during simulation

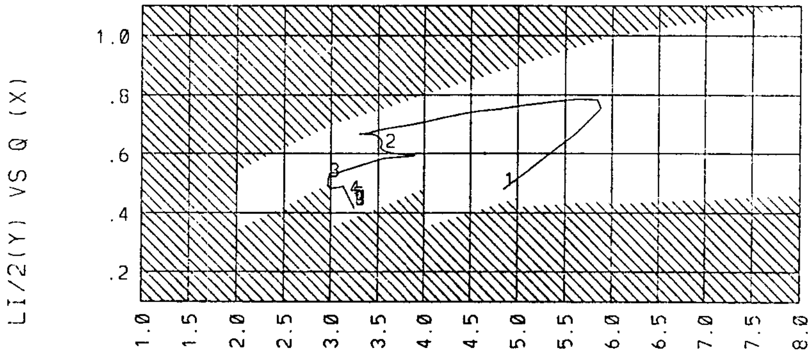

Figure 4 Evolution of β and internal inductance

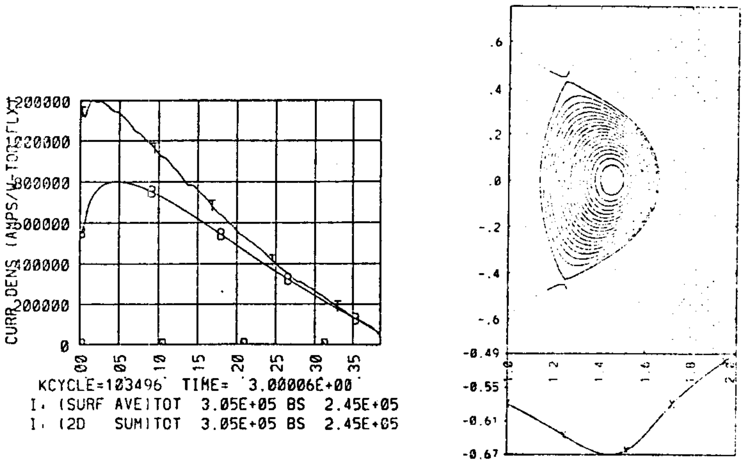

Figure 5 Contours of poloidal flux and current densities