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Simulation Study of Fusion Output Control in DEMO
核融合原型炉における出力制御手法のシミュレーション研究

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Recent results from simulation study of fusion output control in DEMO reactor using integrated 1.5D transport code is presented. Target fusion output is achieved by pellet fueling control based on measurement of neutron detector in combination with edge density control by puff based on density measurement. Conditions to avoid overshoot of fusion output and overcooling of plasma by excessive pellet injection are investigated.

1. Introduction

Conceptual design study of tokamak DEMO reactor is ongoing aiming to start construction in early 2030s. DEMO is charged to show an economical perspective toward to commercial reactor. Thus to achieve and maintain expected fusion output is an essential requirement for DEMO design. There are several new challenges related to output control in DEMO. First, pursuit of economy requests efficient harnessing of autonomous nature of plasma, i.e. large fraction of self-heating and spontaneous current, must be controlled with relatively powerless actuators. In addition, due to severe neutron and heat loads, as well as port area restriction attributed to necessity of sufficient tritium breeding ratio, only limited diagnostics and actuators should be available in DEMO. Robust output control strategy with limited information (such as line-density and neutron detector) with information compensated by simulation will be required for DEMO [1].

In the following, we report the current results of output control study for DEMO by direct pellet fueling to core plasma based on fusion output computed from neutron detection.

2. Short Code Description

For the demand of DEMO control study, integrated simulation code scanning over wide parameter range is necessary. A 1.5D transport code ATLAS is being developed for such DEMO design oriented purpose. While it is based on many common routines with TOPICS [2] (1D transport & 2D equilibrium), ATLAS consists of reorganized independent modules, including, diagnostics (line density, neutron detector), hardware (NBI, puff, pellet, coil, RF, wall). For this conceptual design phase, semi-empirical transport model (Bohm/gyro-Bohm model [3] in this study) is employed. Although it is relatively qualitative compared to TOPICS or TASK[4], it holds fast computation speed so that parameter scan survey with more than 30 cases of 120s discharge is feasible per a night on a standalone workstation.

3. An Example of DEMO plasma

Figure 1 shows an example of DEMO plasma controlled for 1.5 GW fusion output target.

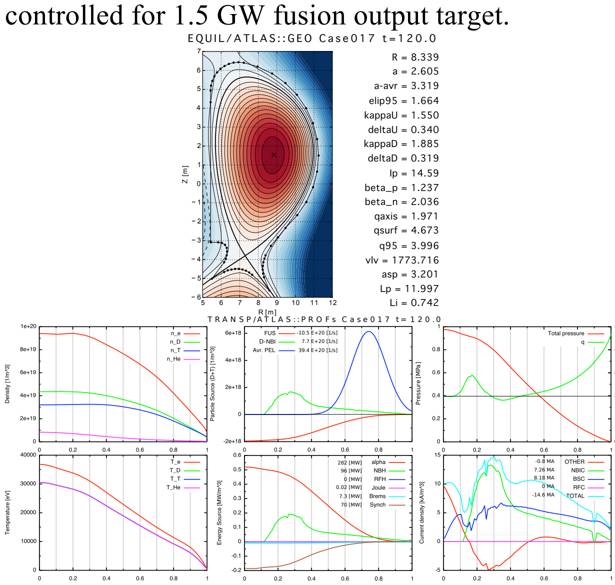

Fig.1. equilibrium and profiles calculated by ATLAS.

1.5MeV Deuterium NBI is applied with 100MW total power. The temperature pedestal is produced by an implemented toy model which reduces heat transport in given region 0.9<r/a<1 into gyro-Bohm level when the heat flux exceeds empirical L-H power threshold. The density is controlled by pellet and puff. The puff is in charge of keeping edge density to 50% of Greenwald density limit. The pellet is injected by feedback control according to neutron detector signal. Because of high Te, current profile is still far from fully relaxed steady state. So it has not reached to true flattop. The time-scale of current profile relaxation at this parameter can be estimated as > 10^4sec. Off-axis NBI is applied aiming at flat q profile, however, because of slow current diffusion, several q=2 surfaces persist. Reasonable burning plasma seems to be simulated as a whole.

4. Control

The fusion output control in this study is carried out by on/off control of pellet injection feedbacked from neutron detector signal with 5Hz sampling rate. A waveform of the corresponding discharge case is indicated in Fig.2.

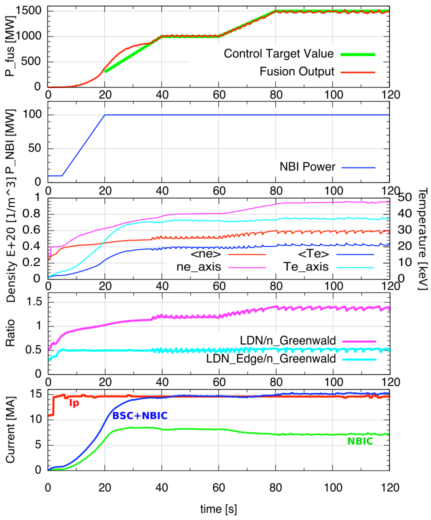

Fig.2. Temporal evolution of output, NBI power, ne, Te, ratio to Greenwald density limit, and currents.

Target of fusion output is shown with green line in the top of Fig.2. There are two main causes of output overshoot in relevant to pellet control. One is insufficient feedback frequency, another is delay of response mainly comes from slow response of temperature profile. In order to avoid overshoot, the target value is changed linearly with finite time longer than confinement time instead of stepwise change. A finite oscillation of output remains as a result of primitive on/off pellet control. It should be mitigated by adequate frequency-based control. Overshoot during 20<t<35 is resulted by puff + particle pinch. In actual situation, puff would be not so effective and edge density should be governed by ELM-pacing pellet [2]. It is beyond of scope of this study.

A trajectory of operation point in <T>-<n> space from another case (with larger pellet) is shown in Fig. 3. Plasma control by pellet results oscillation as shown at (C). The path from N_0T_0 to N_1T_1 pellet deposition event onset in ms order can be approximately treated as adiabatic change. The return journey takes place as transport process (particle loss or consumption); so that heating is effectively shift the point to right direction. Simple analysis shows returning point N_2T_2 is affected by pellet frequency, amplitude of existing heat source, particle transport as well as heat transport. Overcooling can occur when $T_2<T_0$. It means condition to avoid overcooling by pellet depends on unknowable information, i.e. transport, from the viewpoint of control. It is also noted that operation point corresponding to targeted output is not uniquely determined on <T>-<n> space because of the degree of freedom of profiles. The direction and marginal position corresponding to flattop operation point can be affected by balance among these factors in such pellet oscillation cycle. Although the most easy and simple way to avoid overshoots and overcooling is sufficiently slow and gradual variation of the state, for the case of recovery from accident, such constraint in pellet control should become essential. Further analysis will be given in poster presentation.

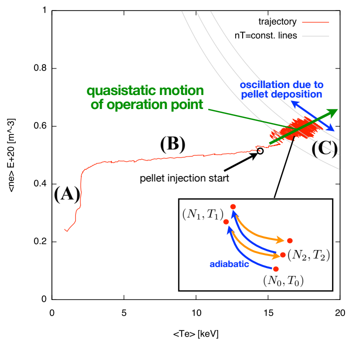

Fig. 3, Trajectory in <Te>-<ne> space

5. Summary

Simulation study of fusion output control in DEMO is performed using simple-fast integrated 1.5D integrated transport code. The target fusion output control is successfully achieved and kept by feedback control of pellet fueling based on neutral detector signal. It is shown that gradual change slower than transport time scale is effective to avoid overshoot. Further analysis is in progress.

References

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