26aE28P

JT-60SAに向けた複合実時間制御と運転シナリオの開発
Development of integrated real-time controls and operation scenarios for JT-60SA

鈴木 隆博, 林 伸彦, 若月 琢馬, 宮田 良明, 本多 充, 井手 俊介
SUZUKI Takahiro, HAYASHI Nobuhiko, WAKATSUKI Takuma, MIYATA Yoshiaki, HONDA Mitsuru, IDE Shunsuke

原子力機構
JAEA

The JT-60SA experiment program [1] is aimed at supporting ITER and providing the physics basis and guidelines for DEMO design having broad conceptual spectrum. In achieving mission goals of ITER and designing DEMO, control, especially real-time control, of physics parameters play an essential role. Successful realization of ITER standard operation at $Q=P_\alpha/P_{ex}=10$ needs control of burning state where self heating by fusion alpha particle (P_α) exceeds external heating power (P_{ex}) for control. In realizing ITER steady-state operation at Q=5 where large bootstrap current at high plasma pressure (normalized beta β_N) contributes to achieve full non-inductive current drive (full-CD) of plasma current, controls of MHD stability at high beta as well as full-CD state are required.

JT-60SA is designed to contribute to development of the control issues above [2]. We have been developing an integrated real-time control system to be applied to and examined in the JT-60SA experiment. The development is carried out on the TOPICS integrated code suite where thermal transport is modeled as CDBM turbulent transport that reasonably well explains the JT-60U experiment [3]. Plasma density profile and pedestal temperature is prescribed to give thermal energy confinement time agrees with the H98(y,2) scaling. The controller under development is a multi-input multi-output controller having a matrix of PID controllers and is flexibly extensible to control of various physics parameters:

$$\begin{pmatrix} P_1(t+dt) \\ P_2(t+dt) \\ \vdots \end{pmatrix} = \begin{pmatrix} P_{PP1}(t+dt) \\ P_{PP2}(t+dt) \\ \vdots \end{pmatrix} + \mathbf{M}\begin{pmatrix} \beta_{\mathrm{Nref}}(t)-\beta_{\mathrm{N}}(t) \\ V_{\mathrm{loop\,ref}}(t)-V_{\mathrm{loop}}(t) \\ \vdots \end{pmatrix},$$

where $$\mathbf{M} \equiv \begin{pmatrix} \mathrm{PID}_{11} & \mathrm{PID}_{12} & \cdots \\ \mathrm{PID}_{21} & \mathrm{PID}_{22} & \cdots \\ \vdots & \vdots & \ddots \end{pmatrix}. \quad (1)$$

The controller (1) feedback controls β_N to its given reference β_{Nref} and loop voltage V_{loop} to its reference $V_{loop\,ref}$ using combination of command output P_1 and P_2 of actuators through PID matrix **M**. The first term of the right-hand-side of eq (1), P_{PP1} and P_{PP2}, is the pre-programmed output to be given prior to control. Our previous work [4] investigated simultaneous controllability of β_N and V_{loop} (essential parameter to full-CD) in real-time in JT-60SA as well as dependence of the controllability on plasma density in TOPICS simulations.

In this study, we have explored integrated real-time control of 3 physics parameters essential in steady sustainment of high beta plasma, namely β_N, V_{loop} and the minimum of the safety factor profile q_{min}. This q_{min} determines the existence of the low-q rational surface at which steep pressure gradient is prone to provoke MHD instability. These parameters, β_N, V_{loop} and q_{min} are controlled by heating power, total CD power and differential current drive power (off-axis CD power minus on-axis CD power), respectively.

We have also developed control scheme of alpha heating where the alpha heating is simulated (numerically here and experimentally in JT-60SA DD operation) using exclusively allocated part of EC+NB heating power. Although study of "real" burning plasma must wait for ITER DT campaign, we hope to investigate a part of burning plasma behavior and develop a controller with this scheme prior to ITER experiment. We show the controllability of the simulated alpha heating at H-mode entry in JT-60SA.

[1] Y. Kamada, Nucl. Fusion **53** (2013) 104010
[2] JT-60SA Research Plan Version 3.2, Chapter 3; http://www-jt60.naka.jaea.go.jp/jt60/pdf/JT-60SA%20Research%20Plan%20Ver.3.2.pdf
[3] J. Garcia, N. Hayashi et al., Nucl. Fusion **54** (2014) 093010
[4] T. Suzuki et al., 40th EPS Conf. (Espoo, 2013) P2.136