USBPO U.S. BURNING PLASMA ORGANIZATION

eNews

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Dear Burning Plasma Aficionados:

This newsletter provides a short update on U.S. Burning Plasma Organization activities. E-News is also available online. Comments on articles in the newsletter may be sent to the Editor (Dylan Brennan) Assistant Editor (Rita Wilkinson). Thank you for your interest in Burning Plasma research in the U.S.!

Director's Corner by C. M. Greenfield

USBPO Leadership Changes

As you are probably aware, Jim Van Dam recently left the USBPO and University of Texas to join the DOE Office of Fusion Energy Sciences as the Director, Research Division. It has been my pleasure to work with Jim in several different contexts, most recently in the USBPO. I wish him the best of luck in his new position, and look forward to continuing to work together in our new roles. With the construction of ITER in its early stages in France, it is an exciting time for our community, and I am delighted to be appointed as the new director. I look forward to working with the US Fusion Energy Science community to advance burning plasma physics and to prepare for participation in a successful ITER research program.

I am perhaps even more delighted that Amanda Hubbard of MIT has agreed to become the new Deputy Director of the USBPO. She previously served as chair of the USBPO Council, and most recently as deputy leader of the Integrated Scenarios Topical Group. Of course, many of you know Amanda from her numerous other community activities and, of course, her scientific work on Alcator C-Mod.

With these leadership changes, this is a good time to look back at the last 5 years, and forward at the years to come. The mission of the USBPO continues to be to "advance the scientific understanding of burning plasmas and ensure the greatest benefit from a burning plasma experiment by coordinating relevant U.S. fusion research with broad community participation." Over the next few months, we will be looking at ways the organization can and should evolve to continue to best serve this mission.

USBPO Activities at the APS-DPP Conference in Salt Lake City

This year the USBPO has again organized a contributed oral session (NO4) "Research in Support of ITER." It will be held on Wednesday, November 16, 9:30 a.m.–12:30 p.m., in Ballroom E, with Chuck Greenfield as session chair.

By the way, another contributed oral session (TO4: "ITER and MFE Physics") also has several ITER-related talks. It will be held on Thursday morning, 9:30 a.m.–12:30 p.m., in Ballroom E. Also, a poster session with ITER-related contributions is GP9, to be held Tuesday morning. On Tuesday evening, 7:30-9:30 p.m., there will be a USBPO Town Meeting on ITER Status. The meeting will be chaired by Michael Bell, Vice Chair of the USBPO Council, and will feature:

- Joseph Snipes, Senior Scientific Officer, Plasma Operations Group Leader, Directorate of

Plasma Operation, of the ITER Organization, will describe the latest developments with ITER and also discuss control systems.
- David Rasmussen, WBS Team Leader for Pellet Injector, ECH & ICH Systems at the US ITER Project Office, will describe the status of heating systems for ITER.
- Réjean Boivin, international leader of the ITPA Diagnostics Topical Group and diagnostics head for DIII-D at General Atomics, will describe the status of diagnostics for ITER and open areas for burning plasma diagnostic development.
- I (Chuck Greenfield) will review US contributions and scientific opportunities for ITER R&D.
- Finally, we will open the meeting up for discussion.

Fall Meetings of ITPA Topical Groups

The schedule for the upcoming meetings for six of the seven ITPA Topical Groups is as follows:

Topical Group	Date	Location
MHD	October 4-7, 2011	Padova, Italy
Transport & Confinement	October 5-7, 2011	Cadarache, France
Pedestal and Edge Physics	October 5-7, 2011	York, UK
Diagnostics	October 17-20, 2011	Hefei (ASIPP), China
Integrated Operation Scenarios	October 18-21, 2011	Kyoto, Japan
Divertor and SOL	2nd week of January, 2012	Jülich, Germany

USBPO Topical Group Highlights

(Editor's Note: The BPO Operations and Control Topical Group works to facilitate U.S. efforts to understand and control the operation of existing and future fusion devices [leaders are Michael Walker (GA) and Egemen Kolemen (PPPL)]. This month's highlight describes some of the most recent developments at DIII-D of controlling the kinetic (or thermal), velocity and current configurations in the experiment, and demonstrates the accuracy to which they can be controlled. BPO members are welcome to propose future Research Highlight articles to the editor.)

Model-based Plasma Profile Control in DIII-D

Eugenio Schuster *(Lehigh University)*

Establishing a suitable current profile has been demonstrated to be a key condition for the achievement of advanced scenarios with improved confinement and possible steady-state operation. The present approach at DIII-D focuses on creating the desired current profile during the plasma current ramp-up and early flattop phases with the aim of maintaining this target profile during the subsequent phases of the discharge. The high dimensionality of the problem, and the strong coupling between magnetic and kinetic variables, motivate the design of a model-based, multi-variable controller that takes into account the dynamic responses of both magnetic and kinetic profiles to the different actuators. Some characteristics of the problem that make it difficult are the limited actuator power, the need to avoid unstable magnetohydrodynamic (MHD) regimes, and the significant nonlinearity of the problem.

The control group at Lehigh University has been working on this problem in collaboration with DIII-D for almost five years. A first-principle control-oriented model of current profile evolution in response to auxiliary heating and current drive systems (Neutral Beam Injection (NBI), Electron Cyclotron Heating (ECH) and Current Drive (ECCD)) and electric field due to induction was developed for the plasma current ramp-up and early-flattop phases [1]. The magnetic diffusion equation is combined with empirical correlations obtained at DIII-D for the temperature and non-inductive current to introduce a simplified dynamic model describing the evolution of the poloidal flux ψ, and therefore the q profile or alternatively the rotational transform $\iota=1/q$ profile, during the inductive phase of the discharge. Optimal

open-loop control schemes were developed based on the simplified control-oriented model [2, 3]. These algorithms predict the open-loop (or feedforward) waveforms of plasma current, neutral beam power, and line-averaged density that are necessary to drive the plasma from a specific poloidal flux initial profile to a predefined final profile during the current ramp-up and early flattop phases. In order to add robustness to the control solution, a reduced-order first-principles model was obtained from the original control-oriented infinite-dimensional model and combined with optimal and robust control theory to synthesize closed-loop controllers [4, 5]. A feedback controller for control of the full plasma current profile was implemented in the Plasma Control System (PCS) and tested experimentally for the first time on DIII-D in 2009. This test was part of a joint experiment by Lehigh University, CEA (Tore Supra), and DIII-D, during which data was also acquired for identification of a dynamic response model for the evolution of coupled magnetic and kinetic profiles during the plasma current flattop [6, 7]. Since that time the profile control capability of the PCS has been expanded to include the possibility of simultaneous control of one magnetic profile ($\psi(\rho)$, $\iota(\rho)$, $q(\rho)$ or $\theta(\rho)=\partial\psi/\partial\rho$) and up to two kinetic profiles such as toroidal rotation and ion temperature. The magnetic profiles are obtained in real time from a complete equilibrium reconstruction using data from the Motional Stark Effect (MSE) diagnostic. Kinetic profiles such as toroidal rotation and ion temperature are measured in real time through Charge Exchange Recombination (CER) spectroscopy. Controllers designed using reduced-order state-space models, which were identified from the acquired data by using subspace identification techniques, have also been synthesized to simultaneously regulate current, rotation and kinetic profiles [8, 9].

The controllers developed from first-principles models use three actuators - plasma current, beam total power and line-averaged density. Controllers developed from identified models use a variety of actuators that can include loop voltage in place of plasma current, individual beam powers instead of total beam power, and total ECH/ECCD power. Magnetic profiles can be controlled at 20 radii (normalized ρ=0.05-1) and kinetic profiles can be controlled at 10 radii (normalized ρ=0.1-1). Each controller is augmented by a model-based anti-windup compensator that overcomes the detrimental effects produced by the eventual saturation of the actuators.

Several versions of model-based, advanced controllers are now under testing in DIII-D, based both on first-principles models and on identified models. Most of the controllers do not have any switch to be chosen or knob to be calibrated since they are based on models and not empirically tuned. Figure 1 shows as an example the effect of a θ-profile feedback controller designed from a first principles model and tested in the recent shot 146153, where control is turned on for $1<t<1.2$, $1.6<t<1.8$, $2.2<t<2.7$ and $3.2<t$ (seconds). The feedforward actuator trajectories (plasma current, total neutral beam power, line-averaged density) are modified by the feedback controller (left) in order to track a desirable target magnetic profile (θ profile) (right). The regulation of the θ profile achieved by the feedback controller before t=2.7 sec, shown in the snapshot for t=2.658 sec (right-top), is lost once the feedback controller is turned off as shown in the snapshot for t=3.158 sec (right-middle). Tight regulation is recovered shortly after turning back the controller on at t=3.2 sec, as shown by the snapshot for t=3.958 sec (right-bottom). The developed model-based profile controllers show potential for expanding present control capabilities in DIII-D and increasing experimental productivity by saving long trial-and-error periods of time currently spent by fusion experimentalists trying to manually adjust the time evolutions of the actuators to achieve a desired current profile at some pre-specified time during the early flattop phase and to sustain it during the rest of the discharge.

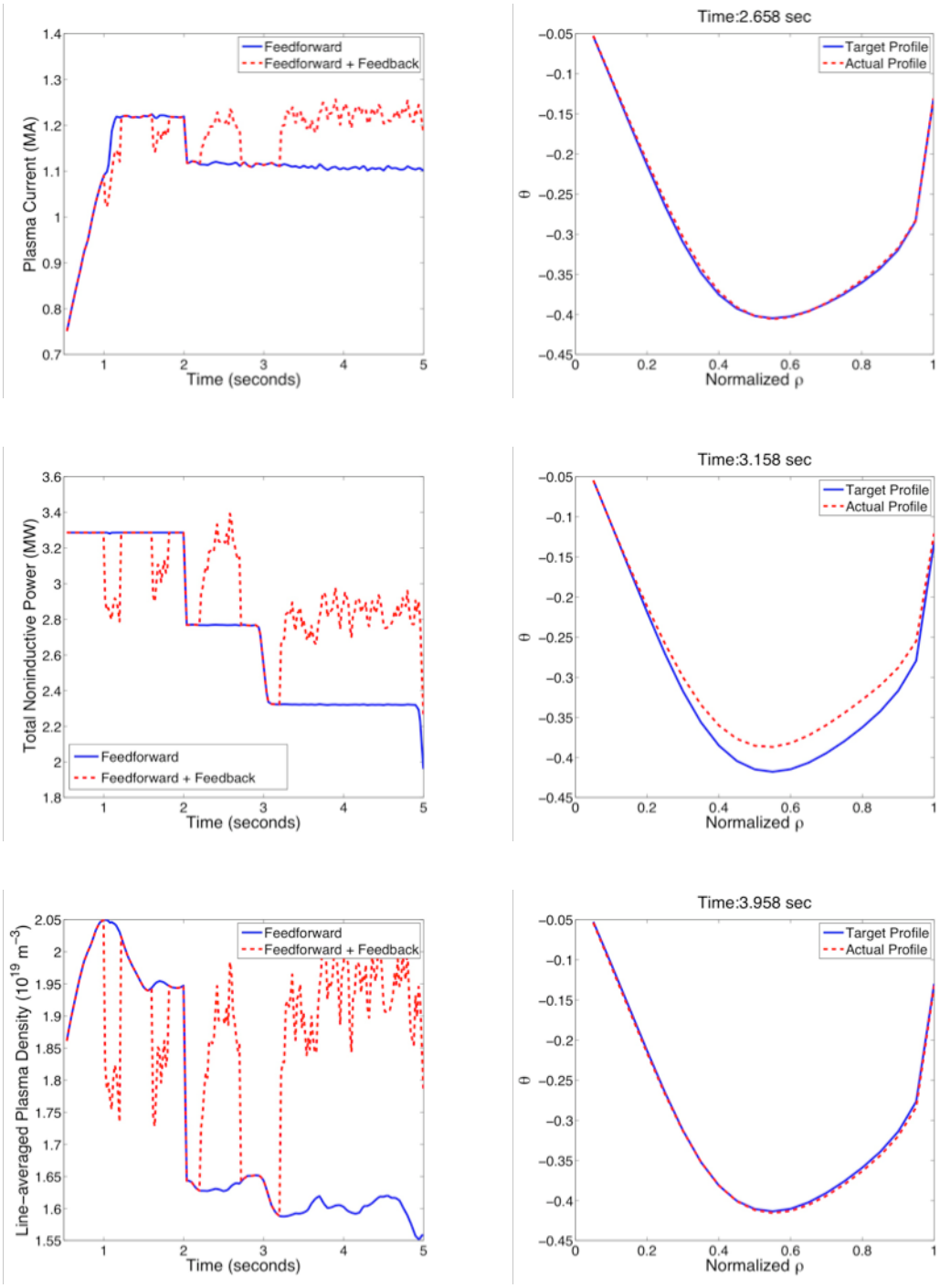

Figure 1: (Left) Correction of the feedforward actuator trajectory by the feedback controller, which is on for $1<t<1.2$, $1.6<t<1.8$, $2.2<t<2.7$ and $3.2<t$; (Right) Comparison of θ profile with it is associated target at three instants of time: t=2.658 sec (feedback on), t=3.158 sec (feedback off), t=3.958 sec (feedback on).

References

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[5] Y. Ou, C. Xu, E. Schuster, T. C. Luce, J. R. Ferron, M. L. Walker, and D. A. Humphreys "Optimal Tracking Control of Current Profile in Tokamaks," *IEEE Transactions on Control Systems* 19 (2), 432-441 (2011).
[6] W. Wehner, E. Schuster, M. L. Walker, D. A. Humphreys, and Y. In "Feedback Tracking Control of Safety Factor and Rotation Profile Evolutions in the DIII-D Tokamak via System Identification," 52nd Division of Plasma Physics (DPP) Annual Meeting of the American Physical Society (APS), Chicago, Illinois, November 8-12, 2010.
[7] D. Moreau et al., "Plasma Models for Real-Time Control of Advanced Tokamak Scenarios," *Nuclear Fusion* 51, 063009 (2011).
[8] D. Moreau et al., "A Two-time-scale Dynamic-model Approach for Magnetic and Kinetic Profile Control in Advanced Tokamak Scenarios on JET," *Nuclear Fusion* 48, 106001 (2008).
[9] W. Wehner, C. Xu, E. Schuster, D. Moreau, D. Mazon, M. L. Walker, D. A. Humphreys, and Y. In "Data-driven Modeling and Feedback Tracking Control of the Toroidal Rotation Profile for Advanced Tokamak Scenarios in DIII-D," IEEE Multi-conference on Systems and Control (MSC), Denver, Colorado, September 28-30, 2011.

Announcements

Submit BPO-related announcements for next month's eNews to Dylan Brennan.

Upcoming Burning Plasma Events

2011 Events

Oct 4-7, 2011
ITPA MHD Topical Group Meeting
Padova, ITALY

Oct 5-7, 2011
ITPA Transport & Confinement Topical Group Meeting
Cadarache, FRANCE

Oct 5-7, 2011
ITPA Pedestal and Edge Topical Group Meeting
York, UK

Oct 10-12, 2011
13th International Workshop on H-mode Physics and Transport Barriers
Oxford, UK

Oct 16-21, 2011
15th International Conference on Fusion Reactor Materials (ICFRM-15)
Charleston, South Carolina USA

Oct 17-20, 2011
ITPA Diagnostics Topical Group Meeting
Hefei (ASIPP), CHINA

Oct 18-21, 2011
ITPA Integrated Operational Scenarios Topical Group
Kyoto University, JAPAN

Nov 14-18, 2011
53rd APS Division of Plasma Physics Annual Meeting
Salt Lake City, Utah USA

Dec 12-15, 2011
ITPA CC & CTP-ITPA Joint Experiments Meeting
Cadarache, FRANCE

2012 Events

2nd week of Jan 2012
ITPA Divertor and SOL (PSI Selection Committee) Topical Group Meeting
Jüelich, GERMANY

Oct 8-13, 2012
24th IAEA Fusion Energy Conference
San Diego, CA

Directories of Other Plasma Events

IEEE Directory of Plasma Conferences
Fusion Ignition Research Experiment (FIRE) Physics Meetings
Fusion Power Associates Meetings Calendar

Please contact the administrator with additions and corrections.