SESSION CD2/EX9

Saturday, 24 October 1998, at 8.50 a.m.

Chairman: Jikang Xie (China)

LONG PULSE OPERATION AND CURRENT DRIVE 2

Paper IAEA-CN-69/CD2/EX9/1 (presented by D. Moreau)

DISCUSSION

M. PORKOLAB: I am surprised by the kind of q profiles you are modelling. They all have $q_{min} < 2$, which are typically unstable for $\beta_N \geq 2$. You need $2.2 \leq q_{min} \leq 2.4$ for good stability at high β_N, and $q_0 > q_{min}$. Can you comment on this?

D. MOREAU: At this stage of our investigations on reactor scenarios involving current profile control for steady-state operation, our aim was to identify the problems related to current profile control only, and possibly to find strategies which would allow us to obtain reliably whatever q-profile is needed for ensuring the MHD stability of high performance, high bootstrap fraction burning plasmas. No stability analysis has yet been done, but we have been trying various target q-profiles for the purpose of testing our feedback control scheme. In fact, you are right, the q-profile should be determined by MHD stability arguments, and in this paper we have tried to show that, once an optimized q-profile is identified, a feedback controller based on the strategy presented here would enable the pressure and current profiles required for sustaining a high Q stable fusion burn to be built up.

Paper IAEA-CN-69/CD2/EX9/2 (presented by Y. Kamada)

DISCUSSION

M.C. ZARNSTORFF: In your sustained plasmas, what is the fraction of bootstrap current relative to the total current and the fraction of driven currents (OH + NBCD)?

Y. KAMADA: In the case of discharge E30006, the bootstrap fraction is 42% and the beam driven current fraction is 23% at I_p = 1.5 MA.

Y.K.M. PENG: My query concerns the results you have obtained from JT-60U for sustained operation of significant $\beta_N H$ values. Could you clarify the limitations on reaching higher $\beta_N H$ values for sustained operation, or on sustainment over long time scales at higher values of $\beta_N H$?

Y. KAMADA: The β_N values are limited by the slow-growing resistive modes, mainly the neoclassical tearing modes. For a higher H factor, we need a more peaked heating profile. In that case, a peaked pressure profile triggers the low-n ideal kink ballooning mode.

R.J. HAWRYLUK: What was B_T in the discharges which sustained β_N values of 2.5-2.7? In the sustained high β_p ELMy H-modes, were the ELMs type I or type III?

Y. KAMADA: B_T was 2.1 T. The ELMs are basically type I in most of the discharges. In the high δ, high q discharges, the small ELMs may be type III. However, we have not established this yet.

V.V. PARAIL: You show two examples of steady-state plasma with two co-existent barriers - edge and core. One has type I ELMs, and the other type III ELMs. Which is better for sustainability?

Y. KAMADA: In the low q_{95} case, type I ELMs were observed. In the high q_{95} case, the small ELMs may be type III. We can sustain good performance in both cases with H factor > 2. For steady-state operation, we have to consider the heat pulses from ELMs. We intend to work on this in future.

Paper IAEA-CN-69/CD2/EX9/3 (presented by B.W. Rice)

DISCUSSION

X. GARBET: It seems to me that, from the point of view of MHD stability in steady-state regime, the duration of the high beta phase should be compared to the resistive (current diffusion) timescale, and not so much to the energy confinement time. In the case where the duration is larger than the resistive time, do you see any systematic limitation due to tearing modes?

B.W. RICE: In general, DIII-D discharges are short compared with the current diffusion time (~5-10 s). However, our long-pulse discharges are long compared with the growth time of resistive NTMs, so the NTMs are still a significant limitation in these discharges.

R.J. GOLDSTON: Your plots on the NTM β_N threshold suggest no ρ^* scaling, whereas the ASDEX team report a strong ρ^* scaling. Have you examined this issue in detail and compared results with other devices?

B.W. RICE: Yes, the DIII-D and ASDEX Upgrade experiments indicate a different ρ^* and ν_* scaling for the NTM β limit in sawtoothing discharges. Collaboration has been set up between DIII-D, JET and ASDEX Upgrade to investigate these differences further.

R.J. HAWRYLUK: In the new regime with infrequent ELMs, were the ELMs type I or type III? If type I, can you operate with type III or small ELMs, and what is the degradation in confinement?

B.W RICE: We believe the infrequent ELMs are type I ELMs, although the ELM frequency does not increase with power, as is typical of ordinary type I ELMs. In other experiments, for example high squareness experiments, we can produce very small ELMs with an internal transport barrier. However, the edge pedestal is significantly reduced in this case, resulting in decreased β_N and H relative to the infrequent ELM regime.

F. PERKINS: Your results, like many others presented at this conference, benefit from $T_i > T_e$. Since higher density serves to bring T_i closer to T_e, can you comment on how your reported performance depends on density?

B.W. RICE: The results in this work are at $n_e/n_{Gr} \sim 0.5$ and we have not done a density scan to see how performance in this particular regime varies. In other DIII-D experiments, there is evidence that decreasing T_i/T_e leads to degradation in confinement, so this is an important topic for further research. With our high power ECH coming on line, we should be able to produce $T_e \sim T_i$ more routinely.

Papers IAEA/CN-69/EXP1/05 and 06 (rapporteured by C. Gormezano)

DISCUSSION

B. COPPI: Have you begun to derive a scaling for the duration of the internal transport barrier?

C. GORMEZANO: Although we can infer some scaling from our heuristic modelling studies (see paper IAEA-CN-69/EX6/1 presented by V.V. Parail), specific scaling studies have not yet been done. So far, we have developed long pulses at high performance with steady-state perspective. These discharges produce a large number of neutrons and have often been limited in duration to save neutron consumption. I hope, in the future, to be able to report on discharges with internal transport barriers that can last 5 to 10 s, which is our limit on JET for high-performance discharges.

Paper IAEA-CN-69/CD2/EX9/5 (presented by T.C. Luce)

DISCUSSION

V.V. PARAIL: In your experiment, you use NBI heating as a leading heating scheme. Did you take into consideration the NBI non-inductive current and particularly its modification due to the T_e rise?

T.C. LUCE: We subtract the measured non-inductive current in a similar neutral beam shot without ECCD to isolate the ECCD. In addition, we correct the measured non-inductive current in the neutral beam case for the dependence on temperature, density and Z_{eff} expected from theory.

A. BÉCOULET: In both your on- and off-axis CD experiments, what is the agreement between the total NI current and the prediction of NBCD + ECCD + bootstrap (both in amplitude and profile)?

T.C. LUCE: The total integrated non-inductive current is usually in rough agreement with theoretical calculations. The profile of the neutral beam current drive is often broader than predicted by Callen's analytic models. The ability to calculate the neutral beam current drive with a full Monte Carlo orbit-following code is being implemented.

R.J. GOLDSTON: Could you perhaps clarify the ratio of the delivered ECCD power vs. the total power available from your existing gyrotrons?

T.C. LUCE: The present system has a rated power through the gyrotron windows of 1.7 MW for 1 s. The maximum power delivered to the plasma in the data shown is 1.14 MW, and other cases have 1.3 MW. The dominant loss in the system is in the coupling of the distorted output beam from the gyrotron to a Gaussian mode in the waveguide. The distorted output is due to limitations in the windows of the present generation of gyrotrons. Future gyrotrons with diamond windows will have Gaussian beam output, which will raise the coupling efficiency.

B. SAOUTIC: In the off-axis CD case, the electric field is non-zero where the current is generated. One can then expect some further acceleration by the electric field of the hotter particles (non-zero CD). What is your estimate of the fraction of the current due to this synergy?

T.C. LUCE: We have only the theoretical predictions of this effect from Fokker-Planck calculations. The codes indicate no significant modification of the current drive efficiency for most cases, and a factor of 4 increase in local electric field would be required to explain the difference between theory and experiment.