GA–A26673

UNDERSTANDING CONFINEMENT IN ADVANCED INDUCTIVE SCENARIO PLASMAS — DEPENDENCE ON GYRORADIUS AND ROTATION

by
P.A. POLITZER, C.D. CHALLIS, E. JOFFRIN, T.C. LUCE,
M. BEURSKENS, P. BURATTI, F. CRISANTI, J.C. DeBOO, J.R. FERRON,
C. GIROUD, J. HOBIRK, C.T. HOLCOMB, A.W. HYATT, F. IMBEAUX,
R.J. JAYAKUMAR, J.E. KINSEY, R.J. La HAYE, D.C. McDONALD,
C.C. PETTY, F. TURCO and M.R. WADE

MAY 2010

GENERAL ATOMICS

DISCLAIMER

GA–A26673

UNDERSTANDING CONFINEMENT IN ADVANCED INDUCTIVE SCENARIO PLASMAS — DEPENDENCE ON GYRORADIUS AND ROTATION

by

P.A. POLITZER, C.D. CHALLIS[1], E. JOFFRIN[2], T.C. LUCE, M. BEURSKENS[1], P. BURATTI[3], F. CRISANTI[3], J.C. DeBOO, J.R. FERRON, C. GIROUD[1], J. HOBIRK[4], C.T. HOLCOMB[5], A.W. HYATT, F. IMBEAUX[2], R.J. JAYAKUMAR, J.E. KINSEY, R.J. La HAYE, D.C. McDONALD[1], C.C. PETTY, F. TURCO[6] and M.R. WADE

This is a preprint of a paper to be presented at the 23rd IAEA Fusion Energy Conference, October 11–16, 2010 in Daejon, Republic of Korea and to be published in Proceedings.

[1]EURATOM/CCFE Fusion Association, Culham Science Centre, Abingdon, Oxon UK
[2]Associatione Euratom CEA, CEA/DSM/IRFM, Cadarache, Saint-Paul-lez-Durance, France; JET-EFDA-CSU Culham Science Center, Abingdon, OX14 3DB, UK
[3]Associazione Euratom-ENEA sulla Fusione, CR Frascati, Frascati (Roma), Italy
[4]Max-Planck-Institut für Plasmaphysik, Euratom Association, Garching, Germany
[5]Lawrence Livermore National Laboratory, Livermore, California
[6]Oak Ridge Institute for Science Education, Oak Ridge, Tennessee

Work supported in part by
the U.S. Department of Energy
under DE-FC02-04ER54698, DE-AC52-07NA27344
and DE-AC05-06OR23100

GENERAL ATOMICS ATOMICS PROJECT 30200
MAY 2010

GENERAL ATOMICS

Hybrid and advanced inductive (AI) scenario plasmas have the potential for long pulse tokamak operation and high fusion yield. We have extended our work in development of these plasmas to addressing issues important to extrapolation of plasma performance to ITER and beyond. First, we have carried out a series of experiments using both JET and DIII-D to develop the scaling of confinement and transport with plasma size (ρ* scaling with other dimensionless parameters fixed – ν*, β_N, q_{95}). A preliminary result of 0-D analysis is that the global scaling is close to Bohm-like: $B\tau_E \propto \rho^{*-(2+\alpha)}$ with α in the range 0.07 to 0.24 (Fig. 1). Also, for well-matched discharges the confinement multiplier, H_{98y2}, depends weakly if at all on ρ*, instead of the strong dependence seen in the ITPA database of hybrid plasmas [1]. 1-D analysis of the profiles obtained for matched plasmas will yield the ρ* scaling for ion and electron thermal diffusivities.

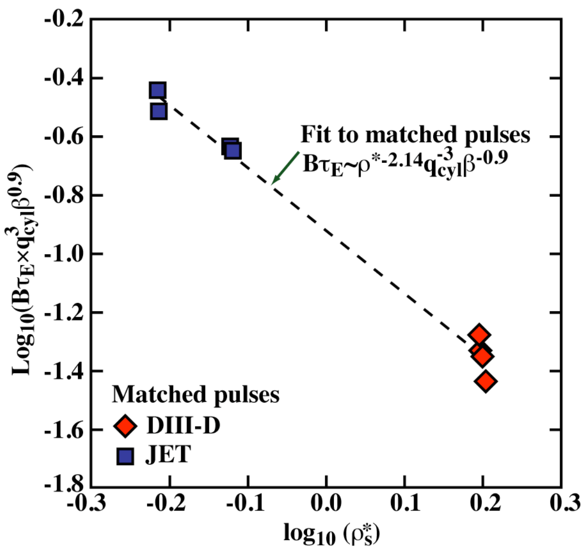

Fig. 1. Scaling of energy confinement with ρ* for 8 matched pulses (4 JET and 4 DIII-D) from the dataset obtained in these experiments, assuming that $B\tau_E \propto q^{-3}\beta^{-0.9}$, as given in the IPB98(y,2) scaling. The parameter $\rho_s^* = B^{-2/3}a^{-5/6}$ is the scaled value of ρ*.

Present experiments also differ from ITER and future tokamaks in the magnitude of the expected plasma rotation and in the electron-ion temperature ratio. The dependence of confinement on rotation and on the presence of a neoclassical tearing mode (NTM) island was determined in a DIII-D experiment in which the applied neutral beam (NB) torque was varied in discharges with similar density and β but a range of q_{95} (3.1–4.9). From the lowest accessible rotation to the highest, a range of ~4.6, H_{89} increased from ~2.0 to ~2.5, with a weak dependence on q_{95} (Fig. 2). The dominant effect is the increase in *ExB* flow shear, with an accompanying decrease in low- and intermediate-*k* turbulence. The effect of decreasing 3/2 island width, while less important, is not negligible. Experiments at DIII-D have also addressed the dependence of confinement on T_e/T_i. Adding electron cyclotron heating (ECH) to a hybrid scenario plasma increased T_e/T_i but also increased energy and momentum transport. Comparing plasmas matched in β and rotation but heated with co-NBI plus ECH versus co- plus counter-NBI showed that the reduction in density often associated with ECH is a consequence of reduced rotation rather than a change in T_e/T_i.

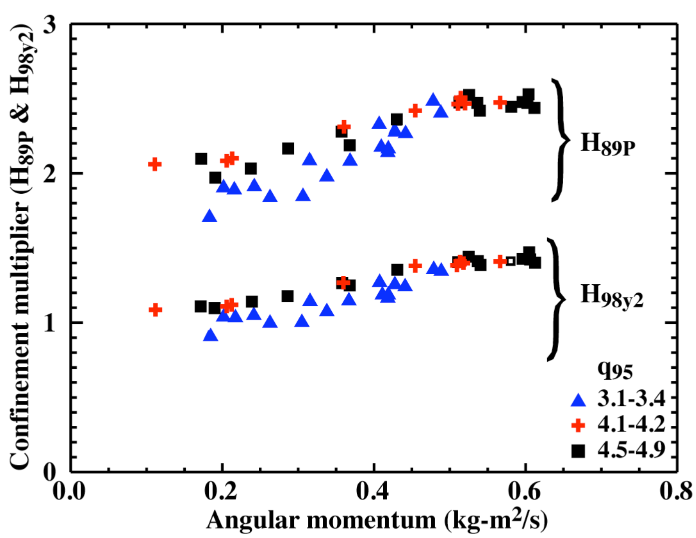

Fig. 2. Dependence of the confinement multipliers, H_{89P} and H_{98y2} on the total angular momentum of the plasma for values of q_{95} as shown in the legend. The values of β_N for these discharges are restricted to the range 2.4-2.6

The dependence of performance on size in AI and hybrid scenario plasmas may not be correctly described by the present empirical scaling rules for standard ELMy H-mode. Determining the depend-ence of performance with dimension-less physical parameters is a robust and rigorous method for develop-ment of scaling laws and for prediction of the characteristics of plasmas in future confinement facilities [2]. Experiments in JET and DIII-D comprise a ρ^* scan across both machines, with plasmas closely matched in terms of aspect ratio, elongation, triangularity, and overall shape. Heating was done with co-injected neutral beams in both devices. The dimensionless parameters ν^*, β, and Mach number were matched to within 20% at the half-radius of the plasma. Between the two devices, data was obtained over a range in ρ^* of about a factor of 3. Although different q profile tailoring techniques are used to establish hybrid discharges in the two devices, the confinement characteristics are similar (e.g., the kinetic profiles are well-matched), indicating the robustness of the scenario. Figure 1 shows the dependence of $B\tau_E$ on ρ^*, assuming that $B\tau_E \propto q^{-3}\beta^{-0.9}$ as in IPB98(y,2) scaling, determined by eight well matched discharges. It was also found that the strong trend of H_{98y2} to increase with ρ^* seen in the ITPA hybrid database is absent for these well-matched discharges. The ITPA database contains unmatched discharges from three tokamaks (AUG, JET, and DIII-D) with different shaping and edge conditions. Each one has been optimized differently, so conclusions drawn about ρ^* dependence are not well supported.

The experiments in DIII-D on the dependence of confinement on rotation were carried out in matched discharges to isolate the dependence on this parameter. The experiments used combinations of co- and counter-neutral beam injection (NBI) with feedback control of β_N. Increasing the rotation by a factor of 3 led to a decrease in the electron and ion thermal conductivities by up to a factor of 2 (depending on radius), with very little change in the density, temperature, or current profiles. The lower q_{95} plasmas were more sensitive to changes in rotation, largely because the NTM island width and radial position increase as q_{95} is reduced. The lower limit to achievable rotation was set by the penetration of error fields and subsequent locking. Further analysis of experiments on the effect of varying T_e/T_i [3] showed that, in addition to the effect on momentum and energy confinement, particle transport is strongly coupled to rotation. The same change in density was seen with the ECH/co-NBI plasmas and the co-/counter-NBI plasmas.

This work was supported in part by the US Department of Energy under DE-FC02-04ER54698, DE-AC52-07NA27344, and DE-AC05-06OR23100.

[1] D.C. McDonald, *et al.,* Plasma Phys. Control. Fusion **50** (2008) 124013.
[2] T.C. Luce, *et al.,* Plasma Phys. Control. Fusion **50** (2008) 043001.
[3] C.C. Petty, Proceedings of the 22nd IAEA Fusion Energy Conf., Geneva, Switzerland (2008).