GA–A22646

EFFECTS OF DIVERTOR GEOMETRY AND PUMPING ON PLASMA PERFORMANCE ON DIII–D

by
S.L. ALLEN, C.M. GREENFIELD, J. BOEDO, D. COLCHIN,
M.E. FENSTERMACHER, D.N. HILL, C.J. LASNIER, R. LEHMER,
A.W. LEONARD, T.C. LUCE, M.A. MAHDAVI, R. MAINGI, R.A. MOYER,
T.W. PETRIE, G.D. PORTER, B.W. RICE, M.J. SCHAFFER, J.P. SMITH,
R.D. STAMBAUGH, T.S. TAYLOR, M.R. WADE, J.G. WATKINS,
W.P. WEST, R.D. WOOD[†] and the DIII–D TEAM

JUNE 1997

DISCLAIMER

GA–A22646

EFFECTS OF DIVERTOR GEOMETRY AND PUMPING ON PLASMA PERFORMANCE ON DIII–D

by
S.L. ALLEN,[†] C.M. GREENFIELD, J. BOEDO,[#] D. COLCHIN,[‡] M.E. FENSTERMACHER,[†] D.N. HILL,[†] C.J. LASNIER,[†] R. LEHMER,[#] A.W. LEONARD, T.C. LUCE, M.A. MAHDAVI, R. MAINGI,[‡] R.A. MOYER,[#] T.W. PETRIE, G.D. PORTER,[†] B.W. RICE,[†] M.J. SCHAFFER, J.P. SMITH, R.D. STAMBAUGH, T.S. TAYLOR, M.R. WADE,[‡] J.G. WATKINS,[◊] W.P. WEST, R.D. WOOD[†] and the DIII–D TEAM

This is a preprint of a paper to be presented at the Twenty-Fourth European Conference on Controlled Fusion and Plasma Physics, June 9–14, 1996, Berchtesgaden, Germany, and to be published in the *Proceedings*.

[†]Lawrence Livermore National Laboratory
[#]University of California, San Diego
[‡]Oak Ridge National Laboratory
[◊]Sandia National Laboratories

Work supported by
the U.S. Department of Energy
under Contract Nos. DE-AC03-89ER51114,
W-7405-ENG-48, DE-AC05-96OR22464, DE-AC04-AL85000
and Grant No. DE-FG03-95ER54294

GA PROJECT 3466
JUNE 1997

EFFECTS OF DIVERTOR GEOMETRY AND PUMPING ON PLASMA PERFORMANCE ON DIII–D*

S.L. Allen,† C.M. Greenfield, J. Boedo,# D. Colchin, ‡ M.E. Fenstermacher, † D.N. Hill,† C.J. Lasnier,† R. Lehmer,# A.W. Leonard, T.C. Luce, M.A. Mahdavi, R. Maingi,‡ R.A. Moyer,# T.W. Petrie, G.D. Porter,† B.W. Rice,† M.J. Schaffer, J.P. Smith, R.D. Stambaugh, T.S. Taylor, M.R. Wade,‡ J.G. Watkins,◊ W.P. West, R.D. Wood,† and The DIII–D Team

General Atomics, P.O. Box 85608, San Diego, California 92186-9784 USA

1. Introduction

This paper reports the status of an ongoing investigation to discern the influence of the divertor and plasma geometry on the confinement of both ELM-free and ELMing discharges in DIII–D. The ultimate goal is to achieve a high-performance core plasma which coexists with an advanced divertor plasma. The divertor plasma must reduce the heat flux to acceptable levels; the current technique disperses the heat flux over a wide area by radiation (a radiative divertor). To date, we have obtained our best performance in double-null (DN) high-triangularity ($\delta \sim 0.8$) ELM-free discharges [1]. As discussed in detail elsewhere [2], there are several advantages for both the core and divertor plasma with highly-shaped DN operation. Previous radiative-divertor experiments with D_2 injection in DN high-δ ELMing H–mode have shown that this configuration is more sensitive to gas puffing (τ decreases). Moving the X-point away from the target plate (to ~15 cm above the plate) decreases this sensitivity. Preliminary measurements also indicate that gas puffing reduces the divertor heat flux but does not reduce the plasma pressure along the field line (in contrast to detached plasmas discussed in Section 2) [3]. The up/down heat flux balance can be varied magnetically (by changing the distance between the separatrices), with a slight magnetic imbalance required to balance the heat flux [4].

The overall mission of the Radiative Divertor Project (RDP) is to install a fully pumped and baffled high-δ DN divertor. To date, however, both the DIII–D divertor diagnostics and pump were optimized for lower single-null (LSN) low-δ ($\delta \sim 0.4$) plasmas, so much of the divertor physics has been performed in LSN; these results are discussed in Section 2. As part of the first phase of the RDP, we have installed a new high-δ USN divertor baffle and pump; these results are discussed in Section 3. Both divertor and core parameters are discussed in each case.

2. Lower Single-Null (LSN), Low-δ Plasmas with Pumping

The open lower divertor pump is shown in Fig. 1. In low-δ lower single-null (LSN) open-divertor operation the cryopump can maintain the plasma density a factor of 2 below the natural density of the ELMing H–mode [5]. A rough figure-of-merit $\eta \equiv n_e\ (10^{19}\ \mathrm{m}^{-3})/I_p$

*Work supported by the U.S. Department of Energy under Contract Nos. DE-AC03-89ER51114, W-7405-ENG-48, DE-AC05-96OR22464, DE-AC04-AL-85000, and Grant No. DE-FG03-95ER54294.

†Lawrence Livermore National Laboratory, Livermore, California.

#University of California, San Diego, California.

‡Oak Ridge National Laboratory, Oak Ridge, Tennessee.

◊Sandia National Laboratory, Livermore, California.

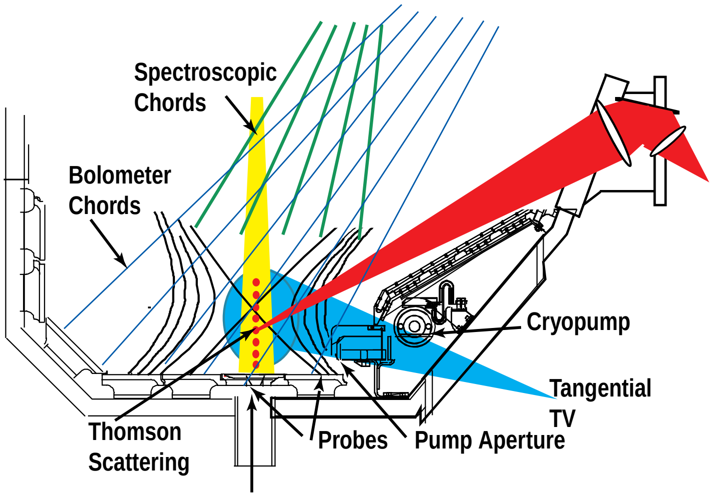

Fig. 1. The LSN low-δ divertor cryopump. There are extensive diagnostics in the lower open divertor.

(MA) is about 5–6 in the natural ELMing H–mode, and can be reduced to 2–2.5 with pumping [6]. With D_2 puffing and pumping, we have sustained radiative divertor operation with only slight degradation in confinement [7], resulting in parameters close to those desired for ITER [τ/τ(ITER-93) ~ 1, Z_{eff} ~ 1.8]. Detailed diagnostic studies [8] have shown that in the divertor: a) T_e ~1–2 eV, b) classical conduction cannot explain the heat flow along field lines at this temperature [9], c) the plasma pressure drops along the field line, and d) recombination is important close to the divertor plate. Carbon is the principle source of radiation near the X-point, with deuterium radiation dominating near the strike point.

Density control in non-sawtoothing ELMing H–mode shots has produced the highest performance long-pulse discharges with H_{89P} ~ 2.4 and β_N ~ 2.8 for up to 2 s, with $n_e = 5.0 \times 10^{19}$ m^{-3} and Z_{eff} ~ 1.8. Transient high performance low-δ LSN ELM-free discharges with negative or weak central magnetic shear (NCS) have also been demonstrated with the pump off [10]. A record DIII–D ion temperature of T_i ~ 25 keV was achieved with τ/τ-(ITER-89P) ~ 4 and β_n ~ 4. This represents a significant improvement over previous single-null discharges. The effectiveness of the pump in ELM-free, low δ, LSN discharges is reduced (particle exhaust ~ beam fueling rate), but reduced wall loading is still possible.

3. Upper Single-Null (USN), High-δ Plasmas with Pumping (New DIII–D Upper Divertor)

The new high-δ DIII–D divertor baffle and pump is shown in Fig. 2; the He-cooled cryopump is the same design as the lower ADP pump. Without plasma, the measured deuterium pumping speed was ~40,000 Torr ℓ/s, similar to that of the lower pump. This system has been optimized for high-δ plasmas, and has a baffle to reduce neutral flux to the plasma core. A combination of the UEDGE and DEGAS codes was used to guide the detailed design of the baffle. For a full double-null installation, the codes calculate that the core ionization should be reduced by a factor of nearly 7. The slanted baffle is water-cooled to prevent racheting of the plate temperature during a succession of plasma shots. Graphite tiles, similar to the those used on the rest of the DIII–D walls, cover the baffle. Careful attention was paid to the gas sealing of the baffle region, including installation of in-situ custom seals. New magnetic pickup coils were mounted on the plate, and these are incorporated into the EFIT shape reconstruction. Real-time EFIT (isoflux) shape control is used to position the plasma in the baffle and sweep the strike points into the pumping aperture. An IR camera views the upper divertor, along with crossed bolometer chords used for tomographic reconstructions of radiated power. Two Langmuir probes near the entrance to he pump aperture are used to measure the ion flux into the pump and an ASDEX-type gauge indicates the baffle pressure.

We have started commissioning of this system with the (unoptimized) USN plasma shown in Fig. 2. This shape has more flux-expansion than the LSN and hence the pump exhaust (and plasma density response) is less sensitive to the strikepoint location. High temperature baking, several (5–6) high power (10–12 MW) plasma shots, and glow discharge cleaning were necessary for initial conditioning of the upper divertor surfaces. Shown in Fig. 3 is a comparison of a shot with the pump warm (92044-dashed) and after the pump was cooled (92062-solid). The core density decreases and the temperature increases for the case with the pump cold. The β_N•H is similar on the two shots. The upper divertor D_α monitors and the midplane pressure (not shown also show a dramatic decrease. Even with limited initial operating time, the density control parameter η achieved has been about 2.5.

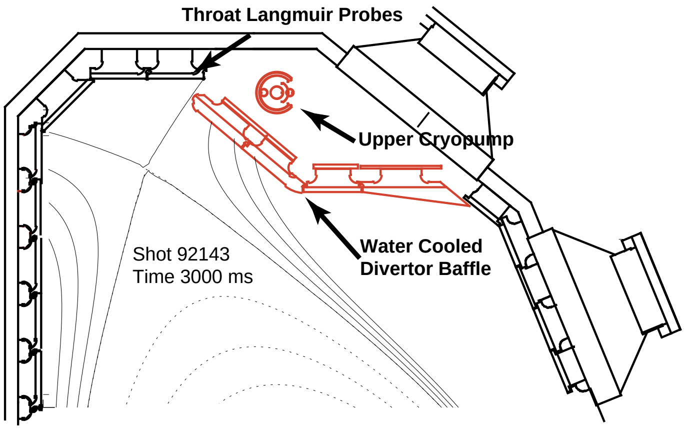

Fig. 2. USN high-δ plasma configuration in new upper DIII–D divertor.

Shown in Fig. 4 is a comparison of a pumped low-δ LSN plasma (shot 89756-dashed) with a pumped high-δ USN non-optimized plasma from the commissioning phase (92144-solid). The ELMing H–mode densities are similar at 2.5 s (although 89756 continues to decrease during the shot) and the core performance in normalized parameters β_N • H(ITER-89P) is similar. (The neutral beam power was greater on 89756, so we have compared normalized performance parameters. The ion temperature and neutron rate were higher on 89756.) As none of the tools used for optimizing the LSN discharge were used with the USN shot (e.g., neutral beam power early in the shot and a reduced target density for NCS), it seems likely that the USN discharge can be further improved with careful discharge tuning.

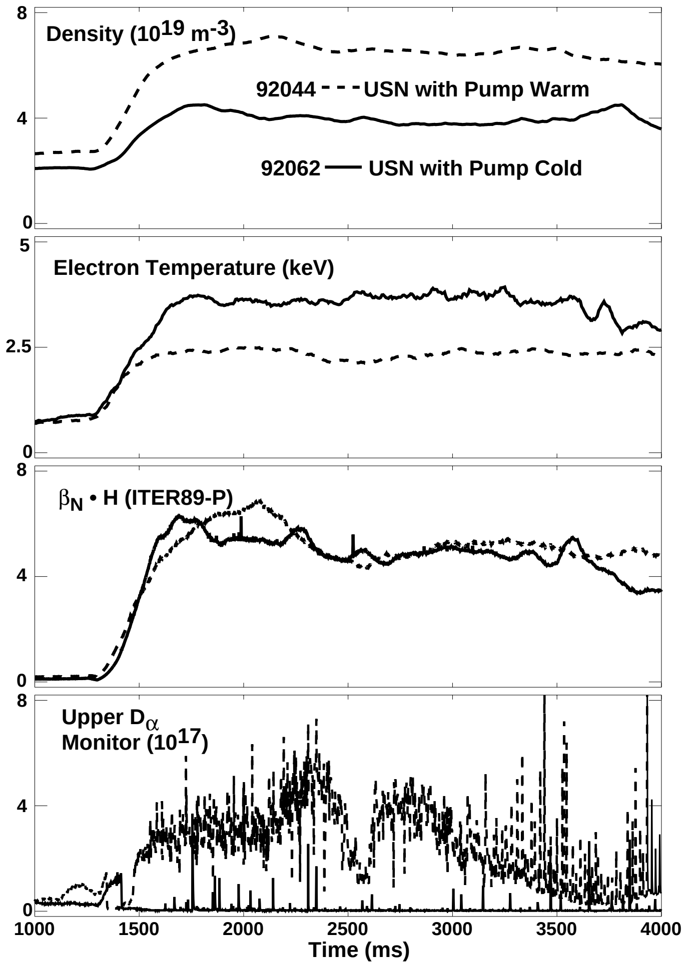

Fig. 3. Initial results showing density control with the upper divertor pump (solid-pump cold, dashed-warm).

In LSN discharges with pumping, a general observation is that there is a dependence of the plasma exhaust on the ELM frequency and size. While a detailed study of the ELM behavior in the new USN discharges has not been carried out, results so far would indicate that density control has been achieved in plasmas with relatively small ELMs at a fairly low frequency (~40 Hz). This very preliminary result will be studied more thoroughly, as we ultimately would like to achieve density control in ELM-free discharges.

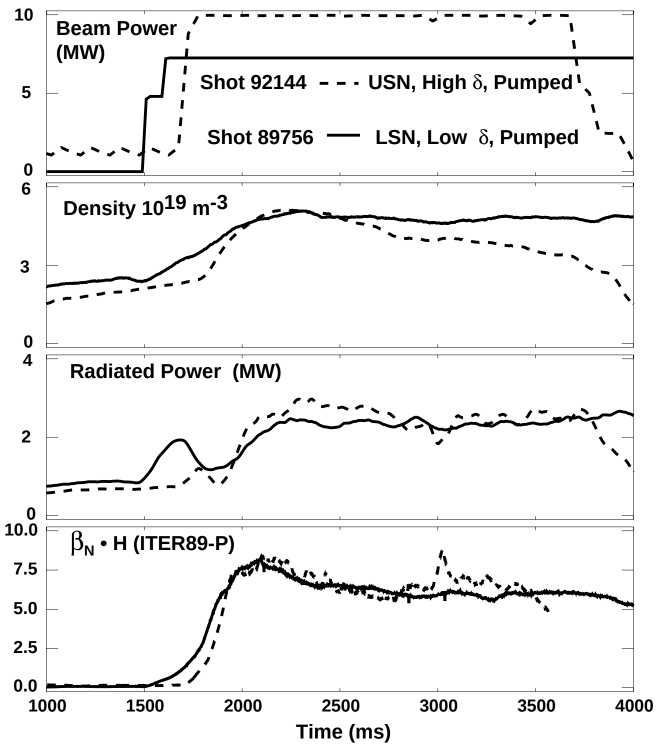

Fig. 4. Comparison of a LSN low-δ pumped discharge (dashed) with an USN pumped high-δ discharge (solid).

We have also carried out initial experiments comparing plasma pumping and core performance with the direction of B_T, and hence the ∇B drift. This drift can influence both the core (higher H–mode threshold with ∇B away from the plate) and divertor plasmas (DIII–D heat flux data becomes more in-out symmetric with ∇B away from the plate). With the lower pump, all experiments have been carried out with the ∇B drift downward towards the divertor plate. So far, with the upper pump, we have not observed any difference in the lowest achievable density due to the direction of the ∇B drift. Subsequent analysis of the data indicates that the ∇B drift upward case is probably not fully optimized, and we will repeat this. In addition, we observe more carbon impurities and 2–4 times more radiated power (although $\beta_N \cdot H \sim 5$ and $T_i \sim 10$ keV in spite of the high impurity levels) in the ∇B upward case. As this could be a conditioning effect, these experiments will also be repeated. USN high-δ bolometer inversions indicate more radiated power on the inside/ (outside) divertor leg for ∇B upward/(downward).

During the coming DIII–D experimental campaign, we will use this new hardware to optimize density control in both ELM-free and ELMing discharges.

[1] E.A. Lazarus, *et al.*, Phys. Rev. Lett. **77**, 2714 (1996).
[2] T.S. Taylor, “Advanced Tokamak Physics,” *these proceedings* (review).
[3] T.W. Petrie, *et al*., Bull. Am. Phys. Soc. **41**, 1430 (1997).
[4] C.J. Lasnier, *et al.*, “Target Plate Heat Flux in Divertor DIII–D Tokamak Discharges,” submitted to Nucl. Fusion.
[5] M.A. Mahdavi, *et al*., J. Nucl. Mater. **220–222**, 13 (1995).
[6] R. Maingi, *et al.*, Nucl. Fusion **36**, 245 (1996).
[7] T.W. Petrie, *et al.,* Nucl. Fusion **37**, 321 (1997).
[8] M.E. Fenstermacher, *et al.*, Phys. Plasmas **4**, 1761 (1997).
[9] A.W. Leonard, *et al*., “Distributed Divertor Radiation Through Convection in DIII–D,” submitted to Phys. Rev. Lett.
[10] E.J. Strait, *et al.*, in Proc. 23rd EPS. Conf., Vol. **20C**, Part III, (1996) p. 1493.