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DIVERTOR AND SCOOP LIMITER EXPERIMENTS ON PDX

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ABSTRACT

Routine operation in the enhanced energy confinement (or H-mode) regime during neutral beam injection was achieved by modifying the PDX divertor hardware to inhibit the influx of neutral gas from the divertor region to the main plasma chamber. A particle scoop limiter has been studied as a mechanical means of controlling particles at the plasma edge, and neutral beam heated discharges with this limiter show similar confinement times (normalized to τ_E/I_p) to average H-mode plasmas.

Two new instabilities are observed near the plasma edge in PDX during H-mode operation. The first, a quasicohherent fluctuation, occurred in bursts at well-defined frequencies ($\Delta\omega/\omega \leq 0.1$) in the range 50 to 180 kHz, and had no obvious effects on confinement. The second instability, the edge relaxation phenomena (ERP), did cause deterioration in the global confinement time. The ERP's are characterized by sharp spikes in the divertor plasma density, H_α emission, and on the X-ray signals they appear as sawtoothlike relaxations at the plasma edge with an inversion radius near the separatrix.

Attempts to obtain high β_T in the H-mode discharges were hampered by a deterioration in the H-mode confinement and major disruptions which limited the achievable β_m . A study of the stability of both the limiter L-mode and divertor H-mode discharges close to the theoretical β boundary, showed that the major disruptions observed there are sometimes caused by a fast growing $m/n = 1/1$ mode with no observable external precursor oscillations.

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MASTER

I. INTRODUCTION

Extensive studies have been made of plasma heating and stability in the PDX tokamak with high power neutral beams [1]. The PDX device operated in several divertor and limiter configurations and in the range $0.7 < B_T < 2.4$ T and $200 < I_p < 500$ kA. A neutral beam injector system provided power levels up to 7 MW with deuterium injection for beam pulse lengths up to 300 msec at 14° from perpendicular at the center of the vacuum vessel.

The original divertor of the PDX tokamak [2] was configured in an open geometry, characterized by low Z_{eff} discharges during ohmic heating and favorable power handling characteristics, especially at high densities, during neutral beam injection. However, high confinement was not observed with neutral beam injection even though some of the characteristics of the transition to the H-mode observed in ASDEX [3] were evident.

In late 1982 the two outer divertor channels were closed off and the neutral gas conductance of the inner channels somewhat reduced by baffles. Divertor plasmas ($R_{pl} = 140$ cm, $a = 40$ cm) in this new configuration provided routine access to better energy and particle confinement times characteristic of the H-mode [4,5]. The closed divertor configuration gave neutral gas compression ratios of 15-30 as opposed to 1 for the open divertor [6] and the energy deposition on the divertor neutralizer plates was ~ 3 times less than the open divertor cases [7].

II. HIGH CONFINEMENT REGIME IN DIVERTED AND SCOOP

LIMITED DISCHARGES

In PDX, the transition to the H-mode confinement regime in a diverted plasma is evidenced by a sharp rise in $\bar{n}_e$ despite a constant gas feed rate. Concurrent with the rise in $\bar{n}_e$, spontaneous rises in volume average toroidal

beta $\langle\beta_T\rangle$ and the total energy confinement time τ_E are observed. The time at which the transition occurs is dependent on the values of I_P , B_T , and the total absorbed power, with typical threshold values ranging from 1-2 MW. Characteristics of a discharge exhibiting the transition into the H-mode are shown in Fig. 1. The abrupt drop in H_α/D_α from the divertor region at the onset of the high confinement phase was used as a criterion to determine whether or not the plasma had experienced a transition from L to H-phase. However, the presence of this transition alone does not guarantee improved confinement, as was concluded from results with the open divertor geometry on PDX during the run period 1980 to 1982 and with forced density rise experiments with the closed divertor [5]. In order to obtain a divertor discharge with good H-mode confinement, it appears that three conditions are necessary: 1) a separatrix must define the plasma boundary 2) a transition must take place, and 3) the particle recycling region should be strongly localized near the divertor throat (i.e., the separatrix x-point in PDX geometry).

Electron density and temperature profiles are shown in Fig. 2a for times prior to the H-mode and well after the H-mode transition, near the peak of the density rise. Density profiles typically broaden just after the transition, and while the electron temperature profiles sometimes broaden they always develop high edge temperatures (~ 400 eV) for good H-mode discharges. Often, as in Fig. 2a, the T_e profile appears to gain a "pedestal," or constant addition, of 200-300 eV at all radii. Detailed measurements of the edge plasma profiles were made with a single point Thomson scattering system. The sharp gradients in T_e ($\partial T_e/\partial r \sim 300$ eV/cm) and n_e ($\partial n_e/\partial r \sim 3 \times 10^{13}$ cm $^{-3}$ /cm) were found to lie just inside the separatrix location in PDX.

The electron temperature changes occurring at the transition from L to H-mode on PBX have been studied in detail with second harmonic electron cyclotron emission [8]. It was found that the maximum fractional temperature rise $\Delta T_e/T_e$ occurred about 5 cm inside the separatrix. The temperature rise at a transition caused by a sawtooth occurred in over $\approx 300 \mu s$. In contrast, if the transition was not triggered by a sawtooth, or if a "fishbone oscillation" [9] caused the transition, then the temperature rise occurred in $\sim 3 ms$. The temperature 5 cm inside the separatrix ranged from 200 to 400 eV at the transition, implying that there is no critical temperature at which the transition will take place.

The energy transport in H-mode discharges was analyzed with the time-dependent transport analysis code TRANSP. Analyses of several cases indicate that the dominant plasma energy loss is through the electron channel, just as it is for L-mode discharges, and this loss is attributed to anomalous electron thermal conduction. The dominant energy loss for ions is through coupling to the electrons, and the ion thermal conductivity is typically 1 to 3 times the Chang-Hinton neoclassical value in order to match the measured central ion temperature.

An independent estimate of χ_e before and after the transition was obtained by an improved form of the heat pulse technique [10]. This method entails not only measuring the time to peak for the heat pulse, but also the time to 3/4, 1/2, and 1/4 the peak temperature. It is found that the χ_e values drop by a factor of two going from the L to H-phase of the discharge. While this technique is only useful for those discharges which have large sawteeth in the H-mode phase, it does confirm the reduction of χ_e obtained from the transport code.

A correlation between improved confinement and a reduction of neutral gas and particle recycling in the main plasma chamber was discovered in PDX H-mode studies by observing a decrease in τ_E as the main chamber neutral gas pressure rose and by comparison of the neutral gas distributions in low-confinement open- and high-confinement closed-divertor discharges. Such an apparent τ_E dependence on the ability to control or localize the particle source raises the possibility of accessing a high-confinement regime via advanced limiter concepts.

Preliminary observations of such an effect were observed in a brief series of experiments wherein circular plasmas were formed on an unpumped particle scoop limiter [11]. In addition to having an enclosed 50% plenum accessed by the plasma via open channels 2 cm behind the limiter surface, this limiter differed from normal rail limiters by its saddle shape and broad front surface (~ 33 -cm wide). While no abrupt transition to a high $\bar{n}_e$ or τ_E regime occurred, neutral beam heated discharges on this scoop displayed values of τ_E similar to those obtained in diverted H-mode plasmas [5,11].

Additional evidence of H-mode-like behavior in scoop limited discharges was high particle confinement times ($\tau_p \gtrsim 100$ msec), and the appearance of a quasiscoherent density oscillation with $f \sim 50$ -150 kHz at $r \sim 0.7$ a. While similar modes at $r \sim a$ were indicative of a good H-phase in a diverted discharge (as described below), they were not seen in L-mode diverted discharges or rail-limited discharges.

IV. MHD ACTIVITY AND FLUCTUATIONS

A. Quasiscoherent fluctuation

A new kind of fluctuation uniquely associated with the the scoop limiter operation and H-mode phase of a divertor discharge was observed on PDX with

both a CO₂ laser interferometer and a 2-mm microwave scattering system [12]. This quasicohherent density fluctuation (Q/F), which always begins within a few milliseconds after the transition from L to H-mode, was observed in a narrow radial range near the plasma edge and was characterized by a surprisingly sharp frequency spectrum.

Frequency spectra of both the broadband density fluctuations and the QCF during the H-mode are shown in Fig. 3 as measured with the 2-mm microwave scattering apparatus. The spectrum in Fig. 3(b) is obtained during the second QCF burst shown in Fig. 3(a). The high frequency bursts (near 120 kHz in Fig. 3) are nearly coherent ($\Delta\omega/\omega \sim 0.1$) for 10 to 20 cycles and are separated by periods of the same duration as the bursts. The wave vector k_y corresponding to the scattering angle for the data in Fig. 3 is in the range between 0.5 and 3 cm⁻¹, (giving wavelengths between 2 and 12 cm or poloidal mode numbers m between 20 and 120 for modes near the plasma edge. Observation with a VUV/X-ray wave detector array yields $m = 15-30$, which is consistent with the lower range of m numbers from the microwave scattering.

While the basic mode associated with the QCF has not been identified, there is a clear one-to-one correspondence between the QCF and the high confinement H-mode regime in diverted plasmas. The large shear near the separatrix tends to stabilize MHD modes, and the narrow radial structure is not characteristic of macroscopic MHD activity. Thus it is more likely that the QCF is electrostatic in character with a magnetic component due to finite β effects.

B. Edge relaxation phenomena

The edge relaxation phenomenon (ERP) which has been observed on PDX during H-mode discharges is similar to that reported by the ASDEX group

[13]. This instability is characterized by sharp spikes on all edge diagnostic signals, such as $H\alpha/D\alpha$ emission, soft X-ray emission at large radii, low-Z impurity emission, edge Langmuir probes, and divertor density signals [14] (see Fig. 1). These edge oscillations are sawtoothlike relaxations located inside the separatrix with an inversion radius at the plasma edge, as seen in Fig. . . The presence of these bursts was correlated with decreases in $\bar{n}_e$, τ_p , τ_E , and $\langle \beta \rangle$, along with an increase in the parallel power flow outside the separatrix. From charge exchange and neutron measurements it was found that ERP's do not cause a significant loss of fast ions.

An important feature of the ERP's is their frequency of occurrence or duty factor. Many experiments were performed in an attempt to stabilize or decrease the frequency of the ERP's. Ramping or decreasing the plasma current during the ERP phase of the H-mode did affect the ERP's frequency but not strongly. One way to increase the frequency of the ERP's was by forcing a density rise by increasing the gas feed rate, which resulted in an ERP repetition rate of ~ 1 kHz. A simple correlation for the ERP frequency was the higher the average level of H_α emission from the divertor region, the higher the frequency of ERP's.

The CO_2 and microwave scattering diagnostics did not detect a clear precursor to the ERP's but in some examples a QCF type density perturbation was detected. The Mirnov coil signals sometimes detected a fast growing magnetic oscillation near the separatrix x-point before the ERP (Fig. 5). This mode was identified as an $m/n = 3/1$ or $3/0$, however the mode amplitude was small and only one or two oscillations were detected before the ERP. Reexamination of old data showed that both the transitions from L- to H-mode and ERP'S were present in PDX open divertor discharges. Since the edge

temperature was not high and no large edge temperature gradient was present in the open divertor geometry, these observations imply that the ERP's are a separatrix and transition phenomenon rather than a temperature or current driven MHD mode.

Results from a poloidal H_{α} detector array indicate that the H_{α} emission starts to rise first in either the divertor dome or the divertor throat region before rising on the mid-plane at the onset of an ERP. A small drop in the H_{α} emission is sometimes observed before the sharp rise for some ERP's. From a toroidal array of H_{α} detectors viewing the divertor region it was observed that the peak of the H_{α} spike at the ERP's are not simultaneous, but are delayed from each other by $\approx 35 \mu\text{sec}$; this delay depends on where the ERP started (Fig. 6). The ERP in Fig. 6a is coupled with a fishbone oscillation [9], and the ERP decreases the amplitude of the fishbone activity. This result implies that an edge perturbation, such as from the fishbone oscillation triggers the H_{α} spike at one toroidal location and then the perturbation propagates toroidally. Figure 6b shows that ERP's can happen independent of fishbone oscillations, indeed this is the most usual situation. From Fig. 6c it is found that the ERP starts near detector $H_{\alpha i}$ and then propagates toroidally.

A scenario which appears to explain the main features of the ERP's is as follows: A perturbation grows in amplitude near the separatrix; this oscillation may cause ergodization of the magnetic field structure and/or potential surfaces near the x-point, thus triggering the discharge back into low mode confinement. The transport is then higher and this causes the edge temperature and density to drop dramatically inside the separatrix, producing the characteristic fast drops (100-300 μs) observed on the soft X-ray signals. From a simple heat diffusion model it is found that 300 μs of L-mode

every 1 ms will roughly halve the increase in confinement due to the H-mode, which approximately agrees with the experimental observations for the intense gas puffing experiment described in Refs. 4 and 5.

V. BETA LIMITS

A crucial issue in defining the role of a beta limit on confinement is the question of what happens as beta limits are approached in H-mode discharges. If improved H-mode confinement were to persist at low B_T and high beam power, the beta values obtained in L-mode (limiter) discharges should be exceeded by up to a factor of two, despite even an L-mode power scaling of $\tau_E \propto P_b^{-1/2}$. However, it was found in PDX that τ_E fell precipitously and β_T saturated as beam power was increased. In part, this may have been due to the strong gas feed required to avoid disruptions in PDX under these circumstances since a large gas feed was shown to destroy the enhanced H-mode confinement. However, the disruptions themselves may have been the sign of the β -limit; they are avoidable only by reducing τ_E (and thus β) through spoiling the H-mode confinement.

Recent numerical calculations on optimization of the current and pressure profiles in tokamaks of various shapes and aspect ratios has suggested a simple scaling law for the maximum volume-averaged β which can be reached before the onset of ideal MHD instabilities:

$$\beta_{\max} = \text{const } \beta_N \quad \text{where } \beta_N \equiv \frac{I_p}{a B_T} \quad (1)$$

where I_p is the plasma current, B_T is the toroidal field at the center of the plasma and the minor radius of the plasma in the equatorial plane [15]. Since β_{TC} can be written as β_T/β_N for fixed R/a and elongation K , a generalized form

of the PDX scaling, $\beta_T q$ versus P_{TOT}/B_T [1], is appropriate for comparing beta boundaries of limiter and divertor discharges in PDX, as shown in Figs. 7a and 7b. The slope of a line through the origin gives an estimate of the confinement time. Some of the rollover of the data at high β_T/β_N is due to a loss of deeply trapped beam ions by the fishbone instability. The increased confinement in the H-mode at low P_{TOT}/B_T is evident from the higher slope of the data compared to that observed for limiter discharges. The inability to increase β_T/β_N over the limiter values and the increased spread of the data at high β_T/β_N implies that the H-mode discharges are subject to the same beta limits as L-mode plasmas.

Taking the upper range of the data in Figs. 7a and 7b to define a beta boundary gives a value of ~ 3.5 for the constant in Eq. (1). Since the calculated values of this constant range from 2.8 for external kink modes to 4.4 for ballooning modes. It appears that the external kink mode limit has been exceeded, but not the $n = \infty$ ballooning limit.

While no additional MHD activity uniquely associated with high β_T/β_N has been found on PDX, many discharges with high β_T/β_N do end with disruptions and some of these disruptions have a fast growing $m/n \approx 1/1$ precursor mode observed in the plasma center by the soft X-ray array. An $m/n = 1/1$ mode is not normally observed before major disruptions in ohmic or low β_T/β_N discharges in PDX. Other disruptions are found to have little or no precursor activity, but the presence of a nonrotating $n=1$ mode can sometimes be identified.

VI. CONCLUSIONS

Plasmas with improved energy and particle confinement times were routinely achieved with the closed PDX divertor configurations over a wide

range of operating conditions. The quality of the confinement in a given H-mode discharge is related to the edge plasma properties and apparently depends on the ability to control neutrals and the location of the plasma fueling source. The improvement in confinement is not sustained at high beam powers in PDX, the deterioration being due to ERP's and intense gas puffing. While preliminary experiments with a particle scoop limiter have produced discharges with confinement values similar to those of the divertor H-mode plasmas, further experiments are needed to explore the possibility of achieving high confinement in a nondivertor discharge.

Two new instabilities have been observed during H-mode operation, the QCF and the ERP's. The ERP's are the most important because they cause a large deterioration in confinement. The ERP's may have a helical nature and are found to propagate toroidally, and in some examples a precursor perturbation with $m, n = 3/0$ or $3/1$ is observed near the divertor stagnation point.

The presence of the beta boundary (β_T/β_N) for both limiter and divertor operation in PDX implies that ideal MHD theory may define the stable operational parameter space for tokamaks. However, no additional MHD activity uniquely associated with high β_T/β_N has been observed, except that major disruptions take place as attempts are made to exceed this boundary.

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REFERENCES

- [1] Johnson, D., et al., in Plasma Physics and Controlled Nuclear Fusion Research (Proc. 9th Inter. Conf. Baltimore, 1982), IAEA, Vienna, 1981 Vol. 1, p. 9.
- [2] Fonck, R.J., et al., J. Nucl. Mater. 111 & 112 (1982) 343.
- [3] Wagner, F., et al., Phys. Rev. Lett. 49 (1982) 1408.
- [4] Kaye, S.M., et al., J. Nucl. Mater. 121 (1984) 115.
- [5] Fonck, R.J., et al., Proc. 4th Inter. Symp. on Heating in Toroidal Plasmas, Rome, 1984, Vol. 1 p. 37.
- [6] Dylla, H.F., et al., J. Nucl. Mater. 121 (1984) 144.
- [7] Bell, M.G., et al., J. Nucl. Mater. 121 (1984) 132.
- [8] Boyd, D., et al., Bull. Am. Phys. Soc. 28 (1983) 1172.
- [9] McGuire, K., et al., Phys. Rev. Lett. 50 (1983) 891.
- [10] McGuire, K., et al., Sherwood meeting 1984, to be published.
- [11] Budny, R., et al., J. Nucl. Mater. 121 (1984) 294.
- [12] Slusher, R.E., et al., Phys. Rev. Lett. 53 (1984) 667.
- [13] Wagner, F., et al., IPPIII/78 June 1982.
- [14] McGuire, K., Joint Conf. of 5th Kiev Inter. Conf. on Plasma Theory and 6th Inter. Congress on Waves and Instabilities, Lausanne, Switzerland June (1984) to be published: Princeton Plasma Physics Laboratory Report PPPL-2134.
- [15] Troyon, F. et al., Plasma Physics and Controlled Fusion 26 (1984) 209; Bernard, L.C. et al., Nucl. Fusion 23 (1983) 1475; Sykes, A. et al., Proc. 11th European Conference on Controlled Fusion and Plasma Physics Aachen (1983), Part II, p. 363.

FIGURE CAPTIONS

- FIG. 1 Discharge characteristics of a two-beam (~ 2.3 MW) divertor plasma with $I_p \approx 350$ kA, $B_T = 1.7$ T. The transition into the H-phase occurs at 450 msec.
- FIG. 2a Electron temperature and density profiles from Thomson scattering for the L- and H-mode phases of a high confinement discharge.
- FIG. 2b Electron temperature and density profiles at the outer edge of the plasma for a high confinement discharge. The shaded regions indicate the estimated location of the separatrix as determined from an MHD equilibrium code.
- FIG. 3 The time record and spectra of microwave scattering from density fluctuations during a PDX H-mode discharge are shown in (a) and (b), respectively. The spectra in (b) with solid line and dotted line are obtained during a time centered at 481 ms and 481.15 ms, respectively. The scattering volume is a predominantly horizontal chord with a length of the order of the plasma radius and a width of 2 cm located midway between the plasma center and the outer separatrix. Heterodyne detection allows the direction of propagation (or rotation) of the fluctuations to be determined from the sign of the frequency shifts.
- FIG. 4 Comparison of an edge relaxation perturbation (ERP) with a normal sawtooth oscillation. The percentage variation in $\Delta A/A$ versus minor radius is shown using the line integrated soft X-ray emissivity signals obtained with a $12.5 \mu\text{m}$ Be filter. In addition the $\Delta T_e/T_e$ from electron cyclotron emission for a ERP is also shown.
- FIG. 5 Magnetic loop activity observed before a H_α spike (ERP) showing some oscillations on coils close to the x-point.

FIG. 6 a) Effects of an ERP on the fishbone activity.

b) An ERP perturbation without a fishbone, showing that H_α emission propagates toroidally.

c) An ERP with a fishbone present, but in this example the H_α spike occurs close to detector $H_{\alpha 1}$.

FIG. 7a) All PDX limiter data for both H^0 and D^0 beams, with fishbone dominated discharges included, on a plot of β_T/β_N (where $\beta_N = I_P/aB_T$) versus P_{TOT}/B_T (I_P in MA, a in meters, B_T in Tesla, β_T in percentage; P_{TOT} is total input power, both beam and ohmic in MW).

FIG. 7b) Similar plot to Fig. 7a for divertor discharges.

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H-MODE TRANSITION CHARACTERISTICS

#84X1196

Fig. 1

Fig. 2

Fig. 3

#84 X1103

FIG. 4

Fig. 5

Fig. 6

Fig. 7(a)

Fig. 7 (b)

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