Preliminary Particle-Scoop-Limiter Measurements in PDx

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ABSTRACT

A plasma edge particle scoop limiter has been installed on the equator of the Princeton Divertor Experiment (PDx), a large tokamak. The scoop limiter is unique in that it is designed such that the plasma plugs the entrance throat thereby impeding the return flow of neutralized gas to the discharge. Neutral gas pressures of the order of 50 microns were measured inside the scoop. The pressure dependence on electron density in the scrapeoff plasma at the throat entrance was stronger than linear.

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In view of the current interest in the use of mechanical techniques for both pumping and impurity control in large tokamaks, a plasma particle scoop was installed in PDX so as to experimentally characterize such a device. In addition this apparatus facilitates controlled experiments related to divertor channel operation without the complexity of typical poloidal divertor magnetics. The concept of the mechanical removal of particles from the plasma edge was put forward by Bieger[1], Schivell[2], and Vershkov and Mirnov[3], and was attempted experimentally on the B-3 Stellarator by Tanner[4] as early as 1966. More recent experimental studies were reported by Talmadge and Taylor[5], and Overskei[6]. This experimental study differs from the other in that the scoop was designed such that the plasma would fill the channel, thereby impeding the back flow of the neutralized gas from it.

A cross section of the particle scoop is shown in Fig. 1. The throat has a length of 21 cm, a width of 2 cm and a depth of 6.3 cm. The end of the throat is a neutralizer plate and the entrance to the plenum chamber, the pressure of which is monitored both by an ionization gauge and a fast response absolute pressure gauge (Bartron). The gauges were mounted in a magnetically shielded box just outside the toroidal field coils of the PDX device, the gauges and plenum chamber being connected by a 130 cm length of 2.5 cm tubing. The installation of the scoop on the horizontal midplane of the vacuum vessel is shown in schematic in Fig. 2. The axis of the throat is rotated 6° out of the horizontal plane such that the local magnetic field lines are parallel to the throat axis for plasma current of 300 kA and toroidal fields of 17 kG in the standard D configuration. The response time constant for the pressure gauges τ , was measured to be 600 ms. As a consequence of this and the fact that the electron density flattops were

shorter than τ , the pressure gauges never reached equilibrium during a pulse. Simple nv arguments show that the plenum chamber pressure is in equilibrium in times very short compared to τ . The interconnecting pipe, as a consequence of its volume and vacuum conductance, can be considered as an integrator, thus the plenum pressure can be estimated from the relationship,

$$\Delta \text{ Gauge pressure} \approx \frac{\text{Plenum Pressure}}{\tau} \times \Delta t.$$

Typical pressure response data showed the linear variation in pressure with time one would expect from the above model. While the experimental scatter proved to be small the absolute values of pressure measured are considered correct to 20%.

The decision to conduct the experiments in the scrapeoff of the standard D were based on the following.

- 1) In this configuration the neutralizer plates would absorb the vast majority of the energy flux, hence removing the necessity of constructing the scoop to be able to handle the thermal loads.
- 2) Probe measurements performed by Budny[7] and Owens[8] have shown that in this configuration for distances of the order of 5 cm outside the separatrix, the plasma density and temperatures are essentially constant. Thus the plasma streaming into the throat can be regarded as homogeneous over the area of the throat (in this plateau region).

These two points together with the knowledge that on PDX most of the energy flows within a cm or so of the separatrix, (Jacobsen[9,10], Owens[8]),

suggested that arranging the particle scoop one to two centimeters outside the separatrix of the standard D would be optimum for the studies of pressure recovery affected by such a device.

The experiments were performed in deuterium discharges where the plateau region electron temperature was measured to be in the 10 to 20 eV range. It was found that the scoop could be positioned anywhere within the scrapeoff to within 1 cm of the separatrix position, with no observable effect on the plasma. All attempts to get closer to and to penetrate the separatrix resulted in disruptive behavior of the PDX discharge, due principally to impurity influx from the overheated scoop.

The variation of the measured plenum chamber pressure as the scoop was driven towards the separatrix is shown in Fig. 3. The points correspond to the axis of the throat; the separatrix occurring at $R = 176$ cms. Pressures were measured over the plasma line density range ($\int n dl$) of $1.1 \times 10^{15} \text{ cms}^{-2}$ to $3.1 \times 10^{15} \text{ cms}^{-2}$, the typical operating range of the $\int n dl$ value for which one obtains a well-behaved PDX plasma with ohmic heating alone. The error bars indicate the experimental scatter in the measurements. The pressure buildup in the plenum chamber increases as the scoop enters the plateau region and then remains essentially constant. The pressure rise is a strong function of $\int n dl$.

Figure 4 plots the plateau pressure rise as a function of $\int n dl$ and it is seen that the plenum pressure rises exponentially with $\int n dl$. This behavior is consistent with the measurements of Owens[8] and of Schmidt and Owens[11] on PDX where they found that $\int n dl$ in the divertor throat rose exponentially with $\int n dl$ measured on the plasma equator.

The maximum pressure rise as a function of the measured electron density in the plateau region is shown in Fig. 5. The dashed line is a theoretical estimate[12] of the neutral gas transport in the scoop. The pressure in the plenum chamber is calculated assuming that the plasma flux on the neutralizing plate is nv_f where v_f is the normal projection of the sound speed. The effects of molecular dissociation, wall collisions, charge exchange, and ionization are included. The plasma in the scoop is constrained to have a prescribed constant density and temperature. This non-selfconsistent treatment yields a linear variation of throat inlet electron density with plenum chamber pressure, the behavior expected if plasma plugging effects influenced only the neutrals. However, the ionization of the neutrals can be expected to increase the plasma density in the throat, thus giving a stronger than linear dependence to the neutral pressure[13]. As can be seen from Fig. 5, the pressure scales much more strongly than linear, indicating that, over the range of measurement, the plasma plugging effects are large. The pressure is seen to scale close to the square of the electron density for the data.

The maximum plenum chamber pressure of ~ 50 microns compares well with the pressure measured by Overskei[6] on Alcator A for discharge line averaged densities on order of magnitude larger than those existing on PDX. Assuming that the edge densities are in a similar ratio, it is seen that the plasma plugged scoop is a very much more effective technique for particle removal from a tokamak discharge than simple passive-limiter/wall pumping schemes.

It is hoped in the future to extend these studies to hydrogen and helium discharges and circular configurations. A scoop limiter capable of withstanding PDX power levels is under development, and these studies will continue once it is installed.

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Fig. 1 Cross section of the particle scoop.

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Fig. 2 Schematic of particle scoop installation in the PDX device.

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Fig. 3 Measured variation of plenum chamber pressure with major radius. The radius data is referenced to the central axis of the throat; the separatrix occurs at about 176 cms.

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Fig. 4 The measured variation in plenum chamber pressure with $\int n dl$ on the plasma equator.

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Fig. 5 The measured variation in plenum chamber pressure with the electron density in the scrapeoff plasma at the particle scoop throat. The dotted line corresponds to the variation computed from the algorithm given in reference (12).