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PUMPED LIMITER DEVELOPMENT ON ISX

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A. Introduction and Summary

Pumped limiter configurations are being suggested for FED and INTOR for helium ash exhaust and fuel particle control.

The goal of the pump limiter studies in ISX is the selection of the most promising concept and its evaluation in the ISX-C device under the following conditions:

1. quasi steady state operation ($\leq$30s)
2. high edge power densities
3. particle control by means of mechanical devices.

We are considering various options, including particle scraper [1] and ballistic particle collection concepts [2] as well as the current FED design [3]. In ISX-B we will test a full-size pump limiter and directly compare the heat removal and particle control capabilities with a bundle divertor. In ISX-C the steady state operation characteristics of pump limiters will be explored.

B. Scoping Studies in ISX-B

The primary objective of the pump limiter scoping studies in ISX-B is, to explore the importance of ballistic effects on the particle collection efficiency. If this concept turns out to be successful in supplying sufficient pumping efficiency, it offers a possibility to design pump limiters without a leading edge [2]. To test the basic concept, a probe-type limiter has been inserted into ISX. The experimental set-up is shown schematically in Fig. 1. The probe consists of two separate, electrically isolated blades intercepting the scrape-off plasma perpendicularly. The plasma particles reflected from one of these blades were partially collected by a tube at the outer end of which the pressure rise was measured. By simultaneously measuring the ion saturation current to the limiter blade, we found a correlation between the incident particle flux and the pressure build-up in the tube which agrees well with model calculations.

In Fig. 2 the measured profiles of pressure rise, ion saturation current and power deposition in the scrape-off layer are shown. All data have been taken at the electron drift side of the limiter. (Experiments on Macrotor indicate that the pressure build-up can be a factor of 2 higher on the ion-drift side [4]. The fraction of particles

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B. Scoping Studies in ISX-B (Cont'd)

reflected per unit length from the limiter blade into the collection tube has been calculated [2] assuming a cosine distribution of the reflected particles and a backscattering coefficient R = 0.5. For the present experimental set-up we expect a fraction of approximately 10% of the incident flux to be scattered into the collection tube. At a line average density $\bar{n}_e = 2.10^{13}$ cm^{-3} the ion saturation current was measured 200 ms into the discharge to be 12.5 A on a limiter blade of 7 x 1.4 cm^2. This yields an average incident flux of 8.10^{18} cm^{-2} s^{-1}. The pressure build-up in the pump limiter has been estimated with a simple model:

$$P(t) = 1/2 \frac{Q}{C} (1 - e^{-(C/V)t}), \qquad (1)$$

where V and C are the volume and conductance of the tube respectively and Q is the particle influx. The time constant $\tau = (V/C)$ has been measured to be 50 ms for D_2 which yields C = 16 ℓ/s for the given volume V = 0.8ℓ. Thus, we should simply see a saturation pressure p = Q/2C with a rise time of τ = 50 ms; the factor 1/2 being due to the recombination of two D-atoms into one molecule in the gas phase. The equilibrium pressure given by Eq. (1) is 2 m Torr for an influx Q = 0.033 Torr ℓ/s. This is close to the measured pressure rise shown in Fig. 2. The equilibrium pressure could only be reached when the plasma density was kept constant for at least 100 ms. This could not be achieved in all experiments. Therefore, the measured pressure rise was sometimes smaller than the equilibrium pressure. At a fixed limiter position the pressure build-up increased monotonically as the plasma line average density was increased, rising to about 3 m Torr at $n_e \approx 6.10^{13}$ cm^{-3}.

The energy deposition to the limiter blades was measured with thermocouples to give an average power deposition per shot. In addition to power deposition and ion saturation current, the electron temperature at the plasma edge (r = 0) was measured by Thomson scattering to yield 40 eV. Thus we were able to evaluate density and temperature profiles in the scrape-off layer by means of the equations

$$j_s = ne\sqrt{\frac{2\,k\,T_e}{\pi\,mi}} \quad \frac{A}{cm^2} \qquad (2)$$

$$\dot{q} = \gamma\,(j^+_{sat}/e)\quad k\,T_e \qquad (3)$$

$$T_e = 40 \text{ eV} \quad (\text{at } r = a),$$

where γ is the heat transmission rate which is assumed to be 7-17 for normal deuterium discharges [5,6].

With a calculated $\gamma \approx 14$ the resulting electron density and temperature profiles revealed a roughly exponential fall-off with e-folding lengths of λ_n = 2.3 cm and λ_T = 4.8 cm respectively.

C. Particle Control with Pump Limiter in ISX-B

In the second stage of the pump limiter development we are going to design a pump limiter that can act as the main limiter. Assuming recycling coefficients of the order of 0.9 and pumping efficiencies of 5-10%, it should be possible to change the total particle outflux N/τ_p by a factor of two when the pump limiter is inserted. This should be sufficient to demonstrate the particle control capabilities.

Since the TiC-coated mushroom limiters [7] have performed well in ISX-B for power loads up to 10 kW/cm^2 the design of the pump limiter will be based on this experience. In Fig. 3 the design is shown schematically for a mushroom shaped limiter inserted from the bottom of the torus. Calculations of particle collection and trapping efficiencies yield approximately 7% pumping efficiency.

D. Integrated 1st Wall/Pump Limiter in ISX-C

The ISX-C device is being designed to accommodate various impurity- and particle control systems. The main emphasis is on steady state operation at high edge power densities ($\approx$30 W/cm^2). A possible pump limiter for heat removal and particle control has to be toroidal in order to provide a large enough area to keep the power load to the limiter at a level of 200-300 W/cm^2. A complete toroidal pump limiter consitutes a major part of the first wall and must therefore be incorporated into the design of the first wall.

As an example of a first wall/pump limiter design, an adaption of the FED pump limiter to the ISX-C device is shown in Fig. 4. A special feature of this limiter is the possibility to control the power deposition at the leading edge by moving the plasma in and out [3]. In the present ISX-C design the first wall is not a continuous vacuum wall. Therefore the pump limiter might need a separate vacuum system in order not to bypass the limiter pumping chamber with the main plasma vessel. The wall next to the limiter is armored to accommodate the enhanced charge exchange flux due to the plasma-limiter interaction. The material of the armor as well as the limiter could be TiC-coated graphite.

References

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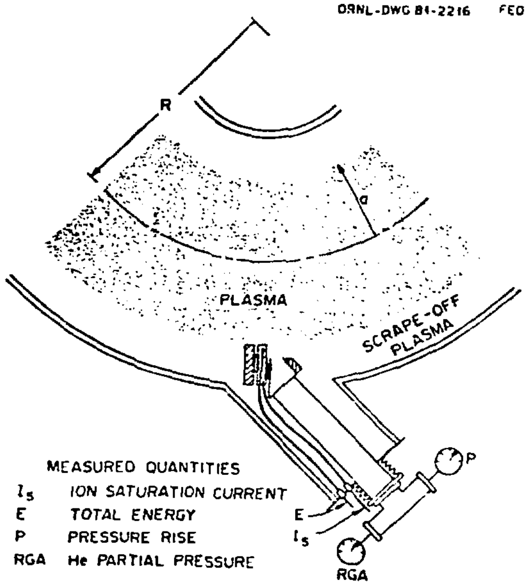


Fig. 1 Schematic of experimental set-up.

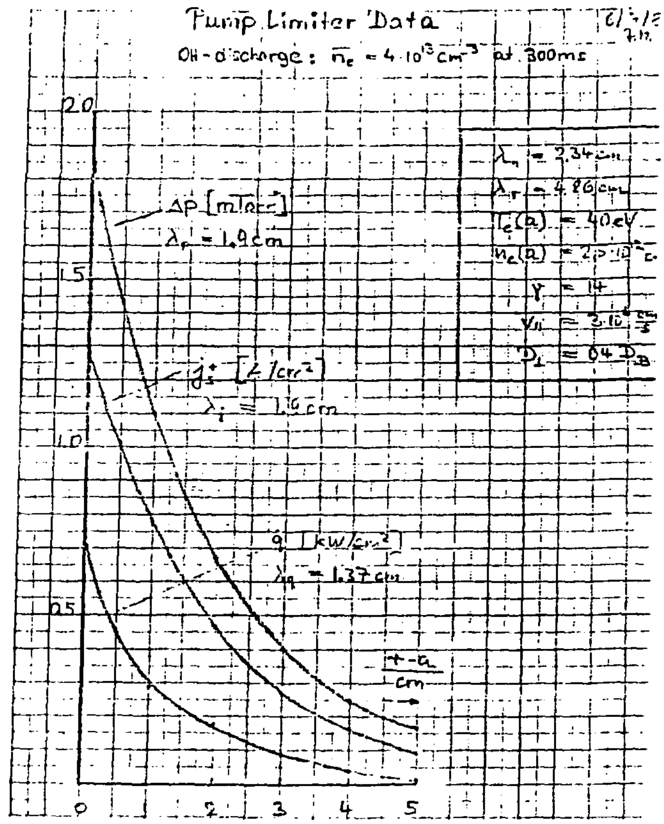


Fig. 2 Profiles of pressure rise, power deposition and ion saturation current.

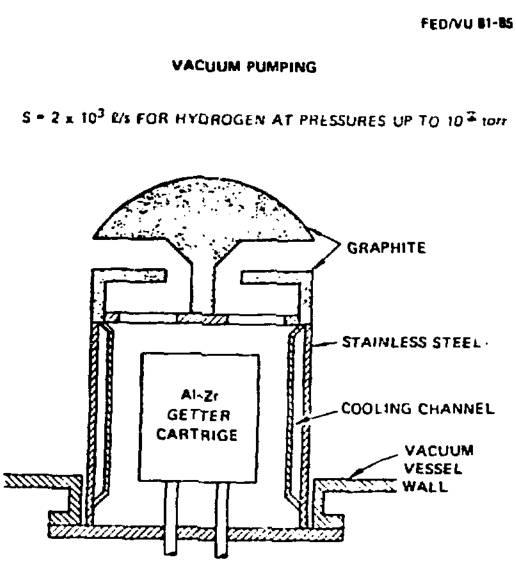
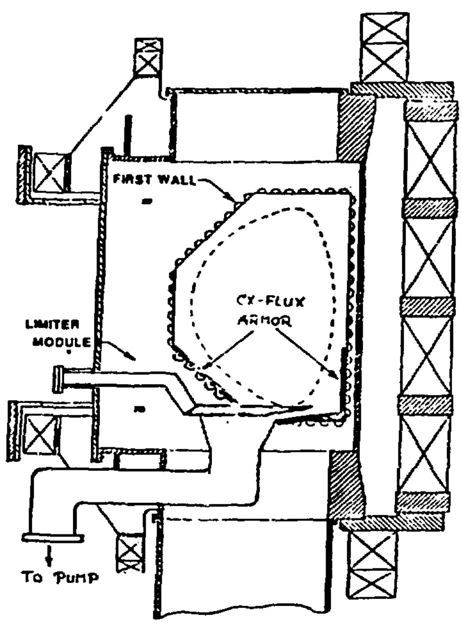


Fig. 3 Mushroom shaped pump limiter wit ı Zr-Al getter pump.



ISX-C modular pump limiter concept.