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THERMAL BARRIER WITH RF

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NEW CONCEPTS FOR DRIFT PUMPING A THERMAL BARRIER WITH RF*

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Pump neutral beams, which are directed into the loss cone of the MX-U plugs, are normally used to pump ions from the thermal barriers. Because these neutral beams introduce cold gas that reduces pumping efficiency, and require a straight line entrance and exit from the plug, alternate methods are being investigated to provide barrier pumping.

To maintain the thermal barrier, either of two classes of particles can be pumped. First, the collisionally trapped ions can be pumped directly. In this case, the most promising selection criterion is the azimuthal drift frequency. Second, the excess sloshing-ion density can be removed, allowing the use of increased sloshing-beam density to pump the trapped ions. The selection mechanism in this case is the Doppler-shifted ion-cyclotron resonance of the high-energy sloshing-ions ($3 \text{ keV} \lesssim U_{\parallel} \lesssim 10 \text{ keV}$).

TRAPPED-ION DRIFT PUMPING

The azimuthal drift frequency ω_D is dominated by the radial profile of the plasma potential: $\omega_D \approx \nabla_r \phi / rB$, where ϕ is the plasma potential, r is the radius in the plasma, and B is the axial magnetic field. In order to pump a sufficient fraction of the trapped ion phase space we must drive a frequency band $\delta\omega_D/\omega_D \sim 0.1, 0.2$. A plot of drift and bounce frequencies in the throttle-coil configuration for particle species of interest is shown in Fig. 1, where the thermal-barrier collisionally trapped ions are represented by species c.

To pump the trapped ions, we wish to impose an azimuthal electric field in the rest frame of the ions to produce radial EXB transport, $E_{\theta} = -\langle \nabla_{\theta} \phi \rangle$. The required field can be estimated as follows:

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$$\tau_{\text{radial}} \lesssim \tau_{\text{fill}} \approx 10 \text{ ms}$$

$$E_{\theta} = Bv_r = \frac{Br_p}{\tau_{\text{fill}}} \approx 0.08 \text{ V/cm} ,$$

where τ_{radial} , τ_{fill} are the barrier pumping and collisional filling times, r_p is the plasma radius, and B is the axial magnetic field. When the expected spatial field profile and the frequency band $\delta\omega_D$ are included, the estimate becomes $E_{\theta} \sim 0.1 - 0.2 \text{ V/cm}$.

PLASMA-POTENTIAL-CONTROL (PPC) PLATE DRIVE

Two methods, driving PPC plates and ponderomotive drift pumping, are presently under consideration for producing the potential perturbation. The PPC plates, are located at $z = \pm 10 \text{ m}$ (Fig. 2) and form the end walls for the plasma. These plates are sectioned so they map to concentric rings at the midplane of the plugs, as shown in Fig. 3. The plates can be driven (as shown) to produce an $m=2$ potential perturbation at $2\omega_D$. The resulting resonant-particle drifts are shown by the arrows.

Because the electron populations do not sample the same axial portion of the plasma potential, they will not, in general, be resonant at the ion-drift frequency. Thus, the resonant drift will not be ambipolar, and shielding by charge separation will tend to occur in any region that is resonant. This shielding can be reduced by axial conduction of passing electrons, either through the barrier to the end plates (greatly reduced during plugging) or to the oppositely phased perturbation in the other plug.

Preliminary experiments were performed, driving only a single PPC plate at each end, to obtain the impedance range for design of the $m=2$ system and to measure preliminary impedance behavior. The rf-input admittance correlated best to the central-cell density and to the end-loss ion current collected by Faraday cups (Fig. 4). The rf-input was not correlated with the total current to the PPC plates (strongly negative current from the hot-electron plug population). The implication is that the rf impedance may depend on the local ion density at the plates and preclude communication of the potential perturbation to the plug during strong plugging operation. Measurements with

the completed double-end, quadrant-drive system, with and without strong plugging, will be required to evaluate this method.

PONDEROMOTIVE DRIFT PUMPING

The second method suggested for introducing the azimuthal potential perturbation is by means of the ponderomotive potential associated with the $m=\pm 1$ slow-wave modes.¹ The potential structure would be of the form: $\phi = \phi(r) \cos 2\theta$, similar to Fig. 3. The antenna required to launch the $m=\pm 1$ modes is a double half-turn antenna. The proposed installation in TMX-U (Fig. 2) is in the east inner fan ($B/B_{\text{midplane}} \approx 1/0.77$) where the plasma will be highly elliptical (Fig. 5).

Waves are launched at a frequency sufficiently less than the ion-cyclotron frequency in the plug to avoid Doppler-shifted resonances ($\omega/\omega_{ci} \lesssim 0.8$ at midplane). The wave coupling efficiency is addressed by use of McVey's antenna code.² Estimates of the resulting ponderomotive potential are then obtained from Yasaka's results¹:

$$S_{\theta i} = \frac{eE_{+0}^2}{2Mr_p \omega_{ci}^2 (1 - \alpha)^2} \left(j_{||} \frac{J_0(vr) J_2(vr)}{vr} \right)$$

where E_{+0} = ion polarization component at $r = 0$, J is the Bessel function, and ω_{ci} is the ion cyclotron resonance frequency. Rotating ponderomotive fields are then obtained by modulating the wave-field amplitude ($\omega_{MOD} = 2\omega_D$). The antenna bandwidth obtainable for this modulation is found by introducing external loading of the antenna and relating bandwidth to the available power, $f_D(\text{kHz}) = 0.06 P(\text{kW})$. (More complex matching networks, which allow broader tuning range at higher circuit Q , are also under investigation.)

The probable factors governing the feasibility of this method will be, first, the difficulty of obtaining a broad enough bandwidth at the antenna voltage level required for adequate drift pumping and second, the necessity of avoiding non-azimuthally symmetric surface electron heating, which would tend to pump the edge of the plasma rather than the core.

SLOSHING-ION PUMPING

Pumping of the sloshing ions would require the same antenna as described for the ponderomotive drift pumping. Power would be supplied at a frequency to make use of the Doppler shifted resonance of the high-energy sloshing ions ($0.8 < \omega_{ci}/\omega_{ci0} < 0.85$) both to select the pumped-ion species and to drive the ions into the loss cone along the heating characteristic (Fig. 6). The advantage of this method is that the antenna need not be modulated, thus requiring less power for a given wave-field strength. Estimates of the required wave field strengths must be completed to allow us to more completely evaluate this method.

REFERENCES

1. Y. Yasaka and R. Itatani, Phys. Rev. Lett. 44, 17630 (1980).
2. B. D. McVey, MIT Plasma Fusion Center Report, PFC/RR-84-12.

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TRAPPED ION SPECIES

f_d = azimuthal drift frequency
 f_b = bounce frequency

Fig. 1. Trapped ion species and characteristic frequencies.

Fig. 2. Axial field profile of TMX-U with antenna position.

Fig. 5. Proposed ICRF drift pump antenna.

Fig. 6. Ion phase space with proposed heating characteristic.

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