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MICROSTABILITY OF TMX-U DURING INITIAL THERMAL BARRIER OPERATION*

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Abstract: During the initial thermal barrier experiments on the Tandem Mirror Experiment-Upgrade (TMX-U), we successfully demonstrated the principle of improved axial tandem mirror confinement achieved by establishment of both the thermal barrier and the ion confining potential peak. During this operation, we created both hot (100-keV) mirror-confined electron and hot (8-keV) mirror-confined ion populations in the end cells. In certain parameter ranges, we observed these species to be weakly unstable to various microinstabilities, but we did not observe clear evidence for an absolute limit to confinement.

1. Electron Microstability Measurements

We used electron-cyclotron resonance heating (ECRH) in the end cells to form the hot electron population. We have achieved energy storage in these electrons in the range of 1.5 kJ, which results in peak betas ($\beta = 2\mu_0 nkT/B^2$) of 15%. Microwave emissions near the electron-

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cyclotron frequency that emanate from this region with power levels far in excess of the "thermal" level (radiation temperature of an equivalent Maxwellian) indicate the presence of instability activity. While these emissions can be intense, 10 to 1000 times the thermal level, they represent power levels of less than 100 W radiated and do not constitute a significant loss of energy. Simil-rly, since we have ECRH efficiencies (energy stored/energy delivered) up to 40%, anomolous loss processes, such as wave-particle scattering into the loss cone, do not appear to be playing a major role.

Using a swept heterodyne microwave receiver to detect radiation along the magnetic field, we observed three distinct bands of enhanced fluctuations. We show three such sweeps from a typical shot in Fig. 1, along with the line integrated density, end loss current, and plasma diamagnetism. We believe that the emissions at frequencies less than 13 GHz observed in Fig. 1a result from whistler unstable waves. We are presently extending measurements to frequencies below 12.5 GHz, the minimum frequency of the present receiver, in order to better resolve this portion of the spectrum. Under conditions of high density, $n_e = 1 \times 10^{12} cm^{-3}$, and diamagnetism, $\beta = 11\%$, we observed the most intense emissions in the 13.5 to 14 GHz band, as indicated in Fig. 1b. Note that 14 GHz is the minimum end cell electron-cyclotron frequency. Fluctuations in this frequency band are consistent with the theoretically predicted unstable range for the cyclotron maser instability. In the plasma decay after ECRH was terminated, we observed emission in the 14.3 to 16.5 GHz band. This is the frequency range for upper hybrid waves that can be driven unstable by the loss cone distribution expected for mirror-confined hot electrons.

For the data presented, we observed no loss in hot electron diamagnetism correlating with these emissions. Similarly, we see no increased axial electron losses during instability activity, as is true in general. For these reasons, we do not believe these instabilities are drastically altering the global confinement of hot electrons. They may, however, be altering the velocity distribution or the spatial structure of the hot electrons; these effects would not be directly observable with our present diagnostics.

2. *Ion Microstability Measurement*

During our most recent experiments, we have extended operation to higher densities by using beam injection of hot ions in the end cells. We injected beams at an angle of 47 deg to the axial magnetic field to produce a "sloshing" (or double-humped), mirror-confined ion distribution existing simultaneously with the hot electrons. This ion population is required to form the potential peak that reflects central cell ions and thus enhances their axial confinement.

Our earlier tandem mirror experiment, TMX, employed perpendicular beam injection and was unstable to an ion-cyclotron mode driven at the minimum ion-cyclotron frequency. In that experiment, we observed particle confinement to be adversely affected by the fluctuations. Theoretically, the sloshing ion distribution employed in TMX-U is predicted to be much more stable to all ion cyclotron modes. In our experiments to date, ion-cyclotron fluctuations are virtually absent at densities below about $1 \times 10^{12} cm^{-3}$. This is true even under conditions in which the axial losses are reduced nearly to zero and their stabilizing effect is negligible. Above this density, weak ion-cyclotron fluctuations are observed using an array of probes at the radial plasma edge. The unstable frequency generally lies near 7.3 MHz, which corresponds to the local ion-cyclotron frequency at the sloshing ion turning point and is 1.8 times the minimum ion-cyclotron frequency. A typical power spectrum indicating the unstable mode is shown in Fig. 2. We have made preliminary measurements of the azimuthal mode number, $m = 17 \pm 3$, from phase shifts across our probe array. This data is consistent with a loss-cone driven mode at the outer (axial) edge of the end cell region.

Since no loss in line density or diamagnetism occurs we observe no dramatic effects on end cell confinement. We do not observe this mode to propagate out of the end cell region as occurred in TMX. Thus, central cell confinement has remained unaffected by the presence of this end cell driven ion-cyclotron mode.

In summary, we observe microinstability of both the hot electron and hot ion distributions in TMX-U. While the electron-cyclotron emissions are fairly intense, much larger than the thermal level, they have limited neither hot electron confinement nor the existence of the thermal barrier. Unstable ion cyclotron modes have either been nonexistent or present only at very low levels when operating at high density. So far the sloshing ion population has not been grossly affected by these fluctuations. We are continuing to study these instabilities as we to push performance of TMX-U to higher density and stored energy.

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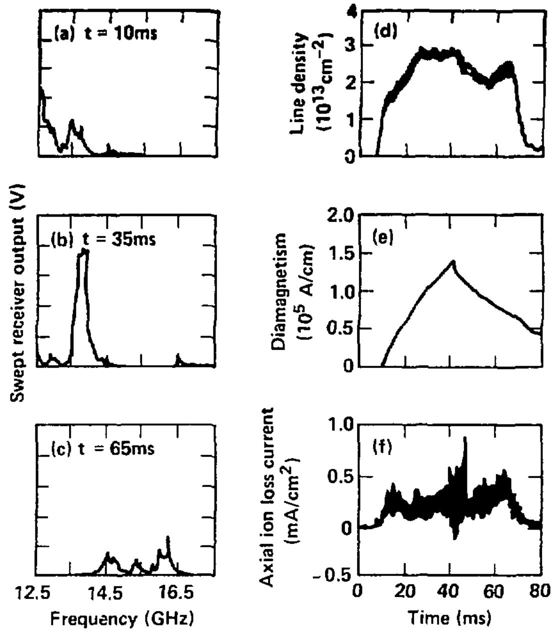
Figure Captions

Figure 1. Typical frequency variation of microwave emissions in TMX-U and the associated experimental conditions. ECRH is turned off at 40 ms.

Figure 2. Power spectrum of potential fluctuations.

T. A. Casper et al. - Fig. 1



T. A. Casper et al. - Fig. 2