Lower Hybrid Experiments on MST

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Abstract. Current drive using RF waves has been proposed as a means to reduce the tearing fluctuations responsible for anomalous energy transport in the RFP. A traveling wave antenna operating at 800 MHz is being used to launch lower hybrid waves into MST to assess the feasibility of this approach. Parameter studies show that edge density is a major factor in antenna/plasma coupling. Gas puffing near the antenna is shown to alter coupling without changing plasma conditions. Hard x-ray emission has been correlated to RF power and is seen to vary strongly with direction of power flow through the antenna.

INTRODUCTION

Experimental and theoretical work indicate that anomalous energy and particle transport observed in the reversed field pinch (RFP) is due to tearing fluctuations. These fluctuations can be reduced when parallel current is added to the edge of standard RFP plasmas [1]. Inductive parallel current drive (PPCD) experiments on MST [2] have demonstrated nine-fold improvement in energy confinement and a tripling of electron temperature. This technique, however, is inherently transient and non-local. RF current drive is an obvious candidate for steady control, and the lower hybrid slow wave has been proposed as a possible choice for the RFP [3].

An antenna with a 20 cm aperture and 4.8 cm wavelength has been designed and built to launch lower hybrid slow waves into MST in order to address the goal of improving transport in an RFP [4]. With the stringent restraints of the MST vacuum vessel, a traveling wave antenna based on an interdigital line [5] was chosen. RF power enters the structure at one end and then propagates to the other end; along the way some power is radiated as a lower hybrid slow wave. Input power can be fed from either end (port direction) with the output end connected to a dummy load.

EXPERIMENTAL OBSERVATIONS

The present antenna operates at 80 kW for 10ms. Anticipated RF power needed for fluctuation stabilization is ~1-2 MW. At present levels of power, coupling and loading issues are the main focus. Power is measured at either feed end and at loops placed along the backplane of the antenna. Figure 1(a) shows RF during a typical discharge. The coupling can be gauged by the power damping length relative to the length of the antenna. Plasma conditions have a strong effect on coupling. The power damping length decreases for high densities and high currents as shown in Figure 1(b). Previous physical models [6] of the coupling in response to plasma conditions do not fully explain the behavior on MST, and this is now an active area of research.

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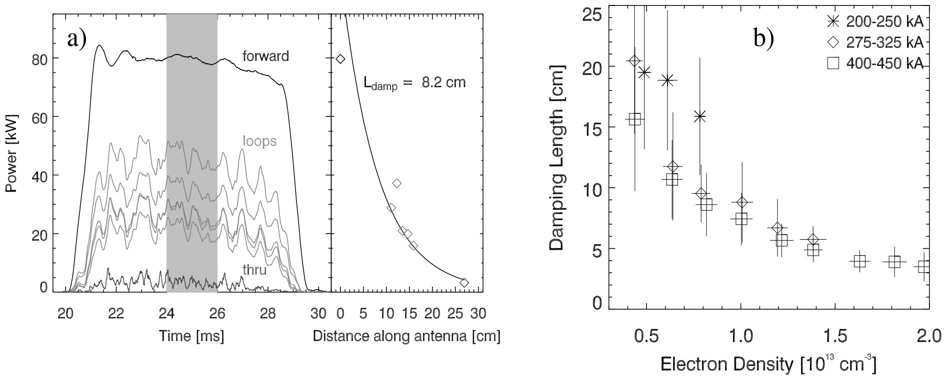

FIGURE 1. (a) Calculation of damping length of RF power flowing down the antenna. (b) Damping Length vs. Density for several different plasma currents.

In high confinement RFP plasmas, the coupling between the antenna and plasma is low. Density profiles show a steep gradient in the high confinement regime, giving a low edge density near the antenna face. Transitions from high to low confinement plasmas with RF power applied have shown a distinct change in the coupling behavior at the transition time. The density profile also flattens at the same time giving an indication that local edge density is a major driver of antenna performance.

To explore the possibility of good RF operation in high confinement plasmas, we attempted to increase the edge density near the antenna with local gas puffing. Similar experiments were done in H-mode plasmas on JET with promising results [7]. Figure 2(a) shows a toroidal cross section of MST with a conduction pipe attached to a puff valve threaded through the pumping duct and terminating approximately 15 cm from the port 2 feed on the antenna. Helium was used and the relative size of the gas input was monitored by an edge-chord spectrometer.

At the time of the experiment, high confinement PPCD plasmas were not reliably obtained, so lower current, low density plasmas were used instead. Although not in a high confinement regime, the antenna also couples very poorly in such plasmas. Figure 2(b) shows the response of the antenna to local puffing for ports 1 and 2 into low density plasmas. For a given line-averaged density, the damping length of the power flow decreases with edge puffing in both port directions. For puffs approximately 50% larger than those displayed in the Figure, the change in damping length becomes more pronounced. This gives confidence that not only can good antenna performance in a high confinement regime be achieved, but also that coupling can at least be increased in other operating conditions.

Hard x-rays are the primary means to detect interaction of the LH wave with the plasma. A fixed array of CdZnTe detectors is positioned opposite and view the face of the antenna. Additionally, several movable detectors allow for crossviews and views toroidally away from the antenna.

Figure 3 shows contour plots of x-ray flux and energy on RF power ramp-up for a

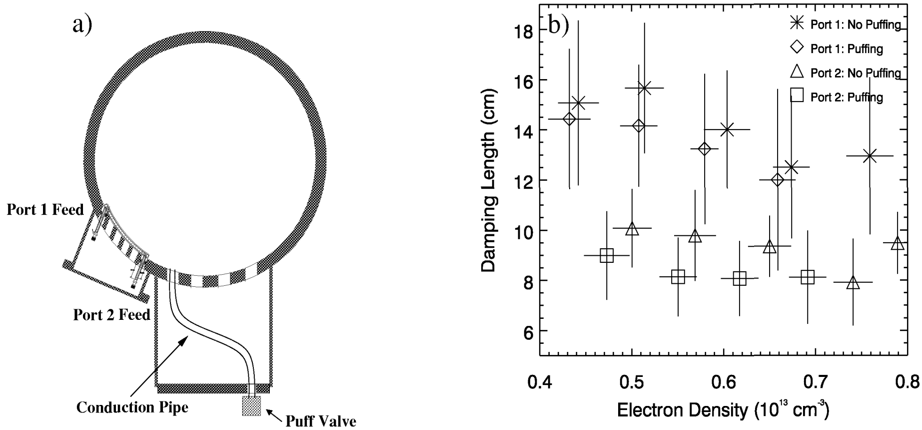

FIGURE 2. (a) Diagram of localized puffing apparatus near the lower hybrid antenna. (b) Damping length vs. line-averaged density for local puffing on ports 1 and 2.

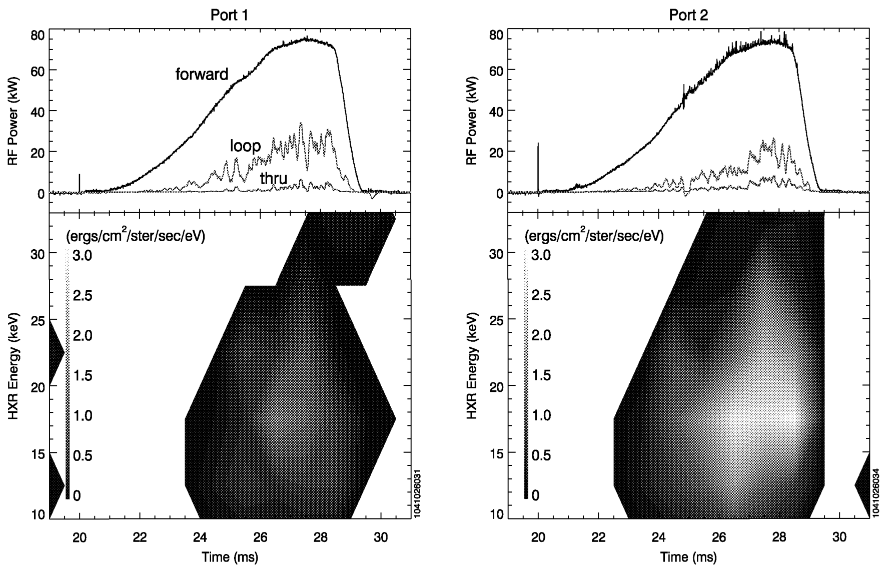

FIGURE 3. Plot of hard x-ray flux vs RF power for both feed directions.

detector viewing the middle of the antenna. There is a threshold for x-ray production that occurs when power is ∼5 kW at the center of the antenna. There is also a notable increase in x-ray flux and energy as RF power increases.

While the overall x-ray energies produced by RF are similar for both power feed directions, power fed from outboard end of the antenna produces a much higher flux than from the inboard feed. The explanation for the flux asymmetry is somewhat of a mystery. In the normal operating regime, plasma electron flow is in the same direction as power flowing from port 1. To test if flow direction is the reason for the difference in flux, the toroidal magnetic field was reversed, causing the electrons to flow in the opposite direction across the face of the antenna. No change in flux was observed with the field reversed. Since the antenna is mounted on the inboard side of the machine, the Shafranov shift brings the port 1 feed farther from the plasma than port 2 and could account for the flux difference in ports. The next generation antenna will test this by constructing the antenna face to be more parallel with the shifted flux surfaces.

CONCLUSION

The LH antenna on MST now runs routinely at 80 kW for 10 ms in a variety of plasma conditions. High confinement plasmas are a natural regime where we would want to operate with RF power. Unfortunately, in those regimes the antenna does not perform well. Recent experiments with local fueling to raise the local plasma density have sucessfully increased the amount of power transmitted to the plasma.

Hard x-ray data indicate plasma interaction even where RF power is well below that needed to reduce fluctuations and transport. Asymmetries in x-ray flux between power feed direction cannot be explained by plasma electron flow direction. Explaining hard x-ray fluxes at this level of RF power and beyond are a major area of current and future research.

The next generation antenna is expected to handle about 300 kW and we hope to see a greater range of plasma effects. More instrumentation on the antenna will enable direct local density measurements and will resolve coupling and power flow to a greater degree.

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