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Electron Bernstein Wave Studies in MST

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Abstract. The overdense plasma in an RFP prevents electromagnetic waves from propagating past the edge, however use of the electron Bernstein wave (EBW) has the potential to heat and drive current in the plasma. MHD simulations have demonstrated that resistive tearing mode stability is very sensitive to gradients in the edge current density profile allowing EBW to potentially be a stabilizing influence. A new MW level experiment is being commissioned on MST to evaluate the potential use of the EBW for current profile control on the RFP. The development of new equipment includes a 5.5GHz klystron driven by a novel switchmode power supply. A quartz window has been constructed and coupling with a cylindrical molybdenum wave guide antenna has been studied. Due to the steep edge density gradient in the RFP, it is possible to efficiently couple to the EBW with O or X mode launch. The EBW is strongly damped at the electron cyclotron resonance where it couples to the electron gyromotion and alters the electron distribution. Either Fisch-Boozer or Ohkawa current drive mechanisms can be activated to drive off axis current in the plasma. Preliminary experiments have been performed to verify high power coupling and understand heating via observed x-ray emission when compared to Fokker-Plank modeling in CQL3D.

Keywords: RFP, electron Bernstein wave, RF, plasma heating, current drive
PACS: 52.35.Hr, 52.25.Os, 52.40.Fd, 52.50.Sw, 52.65.Ff, 52.70.La

INTRODUCTION

The RFP is generally characterized by a high radial energy transport due to multiple large scale tearing instabilities. With only a toroidal applied induction, these current-driven modes are necessary to sustain the RFP equilibrium, as they are responsible for driving the large poloidal current. Good energy confinement in steady state RFP equilibrium will require a current drive profile aligned with the equilibrium current density, which can be tailored to stabilize the tearing fluctuations. This has been demonstrated transiently by PPCD [1].

ECCD is inaccessible in the overdense RFP plasma as X and O mode waves are cutoff very near the plasma boundary; however mode conversion to EBW at the UHR[2] presents an option for heating and current drive at the Doppler shifted EC resonance layer. Electron heating is observed through SXR emission and compared to CQL3D simulations to predict current drive. Demonstration of electron tail heating at 1MW is an important step in determining the feasibility of future EBW current profile control experiments.

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EBW EXPERIMENT

A 1MW 5.5GHz EBW experiment is being commissioned with several improvements over a previously implemented 150kW 3.6GHz experiment. A radar klystron (Figure 1A) designed for several microsecond pulses at a repetition rate of several hundred Hz is being conditioned to generate a 10ms pulse at low duty cycle. The projected pulse is a significant fraction of the typical MST shot length of 60ms and significantly longer than the energy and particle confinement times.

The higher operating frequency allows the use of a smaller waveguide and porthole, limiting fringing field errors in the plasma edge, and potentially improving coupling. The antenna in development is a seamless, cylindrical molybdenum tube supporting the TE11 mode, thereby reducing internal electric field, and improving power handling. While the previous experiment utilized a pulse forming network (PFN), the new system will use a novel switchmode power supply to provide significantly higher input power with greater stability.

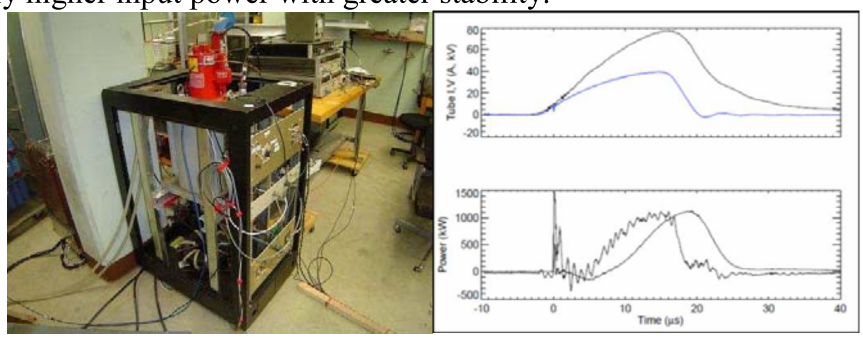

FIGURE 1. (A) Klystron tube and (B) Measured short pulse output (Top: black-tube voltage, blue-tube current, Bottom: tube power measurements through two different detectors. Note: the shift in time between the plots is due to phase lag of an amplifier).

A short pulse PFN was constructed for initial testing of the tube, and generated the necessary -80KV at 40A pulse for several microseconds allowing verification of the full output power of the tube (Figure 1B), and evaluation of window designs at high power. Further testing of the tube in the millisecond pulse length range will commence once construction of the power supply is complete.

The klystron will feed the antenna through a 4 port differential circulator for isolation of reflected power and directional coupler allowing measurement of forward and reflected power for coupling studies. The klystron's rectangular WR187 waveguide is adapted to the antenna by a tapered rectangular to cylindrical transition with an integrated quartz vacuum window.

Several iterations of window design have been tested. Evaluations of a quarter wave resonant choke joint window and pillbox window have been completed. The choke joint window is not optimal for use at high power levels due to high electric field stress across the quartz. Further, the resonant nature of the choke joint produced an extremely sharp pass band that is difficult to center on the klystron output frequency due to variations in quartz dielectric and machining tolerances.

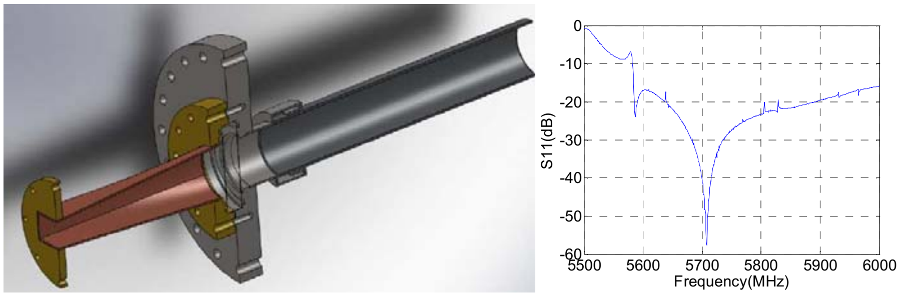

FIGURE 2. (A) Pillbox window design showing tapered rectangular to circular transition, quartz window, vacuum flange, and molybdenum antenna and (B) Pillbox window S11 parameters showing sharp resonance slightly offset from at 5.55GHz.

Testing of the pillbox window (Figure 2A) yielded higher than expected reflection at 5.55GHz due to extreme sensitivity to design parameters, e.g. variations in quartz dielectric, which offset the center frequency from the target value (Figure 2B). Development of a thin (<1/8") quartz window incorporating a stepped pillbox and rounded transition section with offset resonances is currently underway. It is expected that this will allow for a broader pass band with lower design parameter sensitivity. The azimuthally symmetric nature of the window design will allow future experiments at different launch polarization to be conducted without repositioning parts under vacuum. The general design of the antenna assembly as shown in Figure 2A will otherwise remain unchanged from the pillbox window design.

POWER SUPPLY

The klystron will be driven by a switch mode power supply (Figure 3A) capable of delivering -80kV at 40A for the 10ms required to run the klystron. The power supply utilizes resonant transformers (Figure 3B) connected in a three phase Wye configuration.

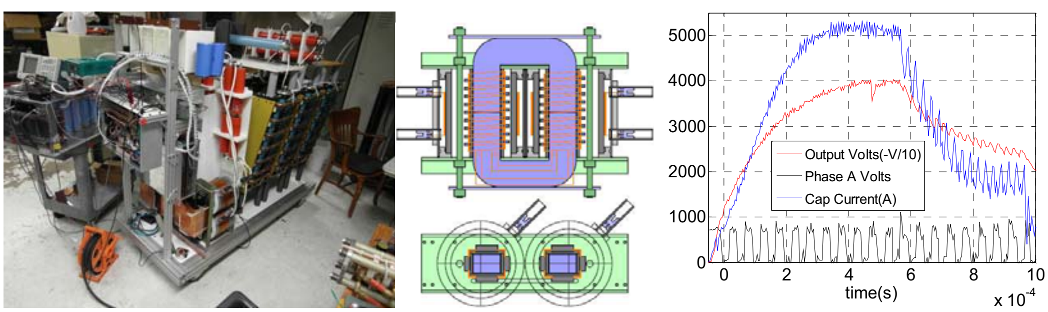

FIGURE 3. (A) Power supply, (B) Resonant transformer design, and (C) Voltage waveform during arc (red:voltage, blue:current, black: phase A primary voltage)

The transformer primaries will be independently driven from a capacitor bank initially charged to 900V through IGBT full H-bridges. The resonant transformers provide a voltage boost greater than the turns ratio and provide a measure of safety with respect to output arcs (Figure 3C), due to the boost ratio's strong dependence on output load. An arc greatly reduces output impedance, decreasing the transformer's boost ratio (Figure 4B) and reducing power supply output. Each transformer features a 10 turn primary and a 136 turn secondary, with a leakage inductance of 1.36mH, in parallel with a capacitor of 50nF yielding a resonance of 19.3kHz (Figure 4A). The assembly of three transformers are operated at or above their measured resonant frequency of 18.5kHz allowing for soft switching of the driving IGBTs. While the transformers only have a 13.5:1 turns ratio, the resonant secondaries will allow a 120:1 boost ratio into the 1800 ohm load of the klystron. At or near resonance, the sinusoidal primary current will be near 180 degrees out of phase with the square wave input voltage, causing the current through the H-bridge to be near zero during the switching event, allowing operation above the IGBT's rated current by reducing switching losses.

The transformer assembly feeds a three phase doubling rectifier and harmonic filter boosting the output to the required -80kV and reducing harmonic noise.

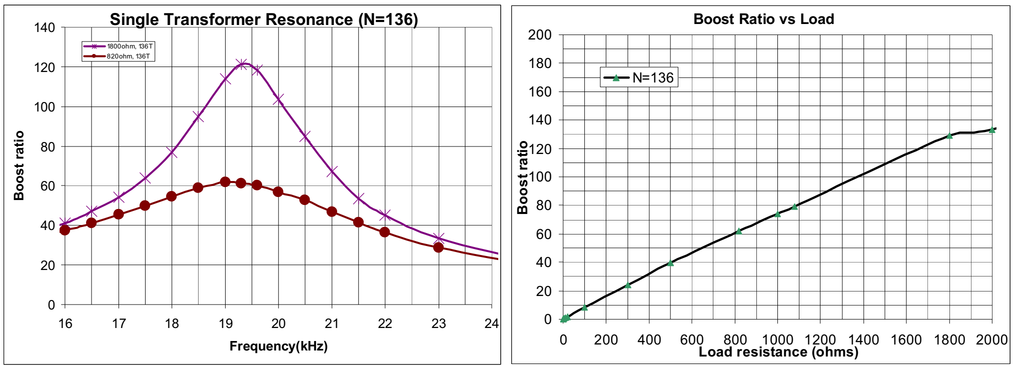

FIGURE 4. (A) Transformer boost ratio vs frequency, and (B) Boost ratio vs Load.

The power supply is controlled with a Microchip dsPIC microcontroller, that will maintain a constant output voltage by tuning the switching frequency closer to the transformer resonance (Figure 4A) as the input voltage from the capacitor bank decreases.

SUMMARY

Design and construction of a high power heating and current drive system featuring a cylindrical molybdenum antenna and quartz window assembly is underway. It was determined that sharp resonances in the window assembly are detrimental to the design by creating difficulty in centering the resonance on operating frequency. A novel switch mode power supply has been constructed to provide suitable power for a high output klystron. The use of resonant transformers allows for boost ratios greater than the physical turns ratio and soft switching operation of the primary IGBTs. This experiment will determine the feasibility of current profile control in the RFP and provide data for an upgrade to a future 4MW system.

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