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The RFTF ECH Microwave System*

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A 200-kW, 28-GHz, cw gyrotron is used to generate an electron cyclotron heated (ECH) discharge plasma in the Radio-Frequency Test Facility (RFTF) at Oak Ridge National Laboratory (ORNL). The facility is used for simulating cw plasma effects on high power Ion Cyclotron Heating antennas being developed at ORNL for fusion energy research. Power from the gyrotron is delivered to the plasma load in 6.35-cm-diam mixed mode vacuum waveguide. The design and operation of this system are described in this presentation.

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The RFTF ECH Microwave System

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A Radio-Frequency Test Facility (RFTF) has recently been constructed at Oak Ridge National Laboratory (ORNL) for development and testing of Ion Cyclotron Heating (ICH) antennas under realistic fusion reactor plasma edge conditions. High-power ICH antennas must be immersed in the plasma for proper coupling of rf power and therefore are subject to particle bombardment and heat flux. In RFTF, plasma is generated and heated by electron cyclotron resonance heating (ECRH) with 28-GHz microwave power from a gyrotron tube. The plasma is confined in a simple magnetic mirror formed by two superconducting coils surrounding a box-shaped vacuum vessel (F1). Using 50 kW of microwave power, a plasma with density of 5×10^{11} cm^{-3} and temperature of 8 eV is obtained, a fairly good fusion research edge plasma. This presentation covers the microwave generation and transmission system plus some of the electron cyclotron heated (ECH) results on RFTF.

The Gyrotron Source

A 28-GHz, 200-kW, cw gyrotron is used as the power source for this sytem. Because this gyrotron and its power supply were previously used on an earlier fusion research device, (R1) Elmo Bumpy Torus (EBT), only the waveguide system had to be added. This gyrotron produces output power primarily in the TE_{02} mode; however, some power is in the TE_{01} and TE_{03} modes due to the simple waveguide tapers in the gyrotron collector. This tube has a dc-to-rf efficiency that can approach 50%.

The gyrotron input power requirements are –80 kV at up to 8 A of current. In addition, an electron gun modulator anode must be biased positive from the cathode by typically 25 kV, which complicates the power supply considerably. The 28-GHz gyrotron uses conventional water-cooled copper magnets to provide the 1-Telsa magnetic field required for cyclotron resonance. Water cooling requirements for the tube are 250 gal/min for collector cooling plus several smaller body cooling circuits, and an FC-75 flurocarbon cooling circuit for the gyrotron output double-disc window. Calorimetry on all of these cooling circuits accurately determines the output of the tube.

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The Transmission System

No attempt is made to use a single-mode transmission system since the gyrotron output is not a pure mode and since the power injected into RFTF is efficiently absorbed after multiple bounces regardless of launch configuration. The design philosophy used in the waveguide run is that if the power is predominantly contained, lower order modes and the waveguide diameter is kept large, then resistive losses and reflections will be small. At 28 GHz with 6.35-cm waveguide, 92 propagating modes possible. The main waveguide component required that can generate other modes is a bend. F2, a diagram of the waveguide run, shows that there are several bends, so it would be difficult to guess which modes contained most of the power at the end of the run. The bends are all radiused bends which generate very little reflection. A system transmission efficiency of 80% has been measured using calorimetry.

Above the gyrotron and before any bends, the power isin circular electric modes TE_{02}, TE_{01} and TE_{03}. These modes have very low loss in the mode absorbers which are placed here to absorb reflected power that is largely in non-circular modes and TM modes. Also above the gyrotron is an optical arc detector to protect the gyrotron window and a small sampling hole for frequency measurement. Simple directional couplers are not useful because the power is not in a single mode.

The entire waveguide is evacuated. This eliminates the need for a barrier window, which is lossy and possibly unreliable in this highly mixed mode position in the system. A good vacuum is required, however, for adequate insulation against arcs. The vacuum pressure is typically kept at 10^{-7} torr by two perforated wall waveguides pumped with a turbo pump. Except for a few initial problems, arcs have not occurried in the waveguide.

Initial tests of the RFTF experiment show a plasma density of 5×10^{11} cm^{-3} and an electron temperature of 8 eV. The plasma profile is flat across the diameter, which indicates uniform plasma production and heating over the resonant surface. The power level has been limited so far to 50 kW or less because of excess X-ray production due to hot electron formation and lack of complete vessel cooling. Additional X-ray shielding and cooling are being added, and an actual ICH antenna test is scheduled soon.

Reference

1. T. L. White et al., "The EBT-S 28 GHz, 200 kW, cw, Mixed Mode Quasi-Optical Plasma Heating System," Int. J. Infrared Millimeter Waves, 5(8) (1984).