Conf-870570--22

CONF-870570--22

DE91 009654

ICH ANTENNA DEVELOPMENT ON THE ORNL RF TEST FACILITY *

W. L. Gardner, T. S. Bigelow, G. R. Haste, D. J. Hoffman, and
R. L. Livesey
Oak Ridge National Laboratory, Oak Ridge, TN 37831

ABSTRACT

A compact resonant loop antenna is installed on the ORNL Radio Frequency Test Facility (RFTF).[1] Facility characteristics include a steady-state magnetic field of ~ 0.5 T at the antenna, microwave-generated plasmas with $n_e \sim 10^{12}$ cm^{-3} and $T_e \sim 8$ eV, and 100 kW of 25-MHz rf power. The antenna is tunable from ~22-75 MHz, is designed to handle ≥1 MW of rf power, and can be moved 5 cm with respect to the port flange. Antenna characteristics reported and discussed include the effect of magnetic field on rf voltage breakdown at the capacitor, the effects of magnetic field and plasma on rf voltage breakdown between the radiating element and the Faraday shield, the effects of graphite on Faraday shield losses, and the efficiency of coupling to the plasma.

ANTENNA DESCRIPTION

A compact resonant loop antenna was made especially for component development and testing on the RFTF. A sectional view of this antenna is shown in Fig. 1. Radio Frequency power is fed to the antenna through a 50-Ω coaxial feedthrough, which serves as a low-loss, low-VSWR, vacuum-to-pressure interface. The antenna's resonant structure consists of an inductive "current strap" or radiating element and an adjustable commercial vacuum capacitor. Between the current strap and the plasma is a two-tiered Faraday shield. Two types of Faraday shield tubes were tested. One type consisted of copper plated over stainless steel tubing; the other consisted of graphite tile armor facing the plasma. Each tile is 2.54 cm long by 0.188 cm thick and is brazed to a copper-coated Inconel tube. These tiles cover nearly half of the tube surface. Lossy elements of the antenna (including the capacitor, current strap, and Faraday shield) are water cooled. By means of capacitor adjustment, the antenna is tunable from ~22-75 MHz. Water cooling should allow the antenna to couple ~1 MW to the plasma under steady-state conditions.

ANTENNA TESTING

At the time of this writing, 100 kW of 25-MHz rf power was available for studying antenna characteristics and limits. This is sufficient for observing high voltage and current behavior under no-plasma load conditions. The only loading is then produced by the Faraday shield (~15 mΩ for copper-plated tubes and 42 mΩ for graphite-tiled tubes) and the rest of the antenna circuit (30 mΩ). Maximum currents and voltages in the antenna under these conditions reach 1400 A and 35 kV, respectively, for the copper shield and 1200 A and 31 kV for the graphite shield. The antenna was initially tested to these levels for 100-ms pulses every 4 s with no magnetic field and pressures less than 10^{-6} torr. Interestingly, capacitor ratings are 650 A and 30 kV. No change was observed in voltage holdoff as a

*Research sponsored by the Office of Fusion Energy, U. S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

function of pressure (hydrogen) up to at least 10^{-3} torr. Variation of only magnetic field at first showed breakdown occurring at relatively low fields with improvement at high fields. Examination of the capacitor revealed arc tracks in the vicinity of the metal-to-ceramic seal. By adding a field grading or corona ring at this point, breakdown was eliminated over the full range of field values as indicated in Fig. 2. Initial voltage holdoff results were taken with a current-strap-to-Faraday-shield gap of 2.5 cm. This gap was reduced to 0.7 cm without affecting holdoff (i.e. breakdown strength across this gap is greater than 50 kV/cm). Figure 3 shows the effect of pressure on voltage breakdown at full field. Voltage holdoff decreases dramatically with pressure above 1-6 x 10^{-4} torr. Fortunately, this pressure regime is nearly an order of magnitude above that expected in a tokamak under any credible circumstances.

Plasma loading as a function of rf power for various microwave input powers is indicated in Fig. 4. Generally, the plasma loading is small (~400 mΩ/m) but sufficient (~75% efficiency.) This indicates that 400 kW would be needed to test to equivalent conditions without loading. However, we did operate at a full 100 kW cw with plasma. The small loading is the result of low plasma density (2-5 x 10^{11} cm^{-3}) and low frequency (25 MHz). Loading observed on the DIII-D antenna, which is similar to this antenna, operating at 55 MHz and higher plasma densities, is significantly higher (~2 Ω).[2]

Of importance to present antenna designs (e.g., TFTR and Tore Supra), is the fact that the use of graphite as a Faraday shield material means no significant change in antenna operating characteristics. This was confirmed in all of the following combinations of scenarios: pulsed or cw operations in the presence of gas, magnetic field, or plasma. At 100 kW, even with plasma, the sustained electric field between the current strap and Faraday shield was greater than the design specifications for TFTR and Tore Supra. The only significant difference this Faraday shield makes to antenna performance is to increase the unloaded rf resistive losses by 42 mΩ. This increase in loss is considerably less than was expected based on published resistivity losses for graphite, and may be caused by the specific type of graphite used. Because losses are much less than expected, thermal stresses and heat loads will be much easier to deal with in antenna design.

CONCLUSIONS

The RFTF was used to test important principles being used in antenna design. Specifically, we have demonstrated that capacitive structures can be operated at or beyond voltage ratings in the presence of magnetic fields and plasmas. It was shown that graphite Faraday shields do not compromise antenna performance; thus, antennas can have a graphite-to-plasma interface to minimize contamination. In addition to these concepts, which are incorporated in the DIII-D, TFTR, ATF, and Tore Supra antenna designs, we have also refined structural cooling techniques, field grading structures, and capacitor attachment techniques. Finally, we are beginning to document breakdown characteristics as a function of power, magnetic field, gas, and plasma. Although we do not yet have enough power to push the limits with plasma, the currently documented limits serve as a guide to what is credible for design purposes. These factors (proven principles, demonstrated details of design, and characteristics of breakdown) are required to ensure that our ICRF antennas work.

REFERENCES

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2. M. J. Mayberry et al., Bull. Am. Phys. Soc. **31**, 1418 (1986).

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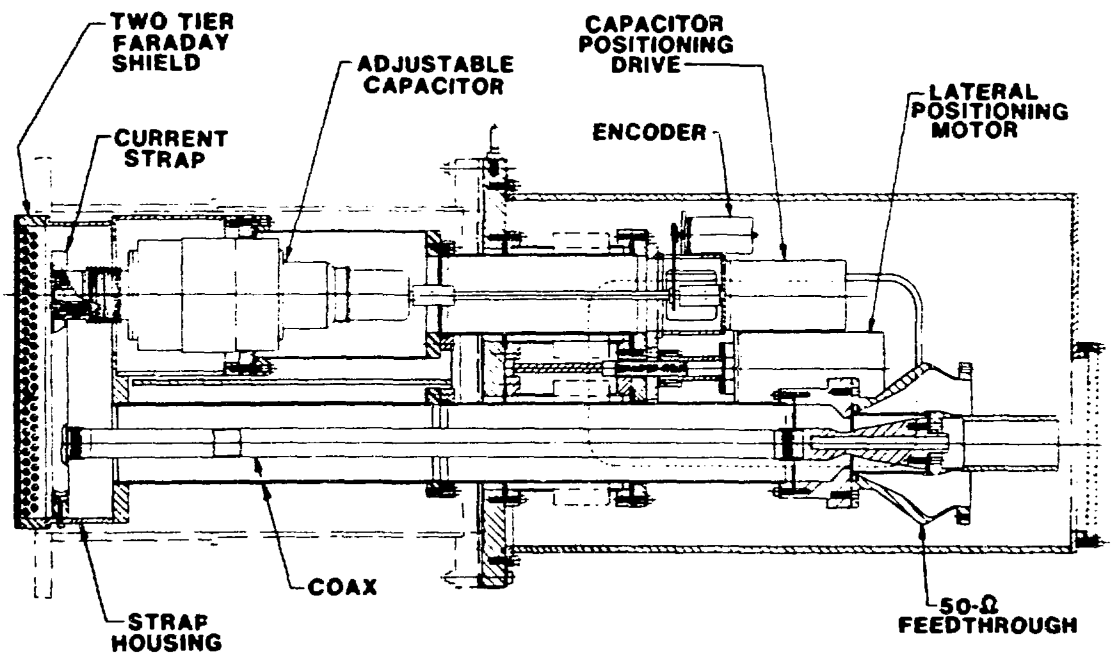

Fig. 1. Sectional view of the ORNL compact resonant loop antenna.

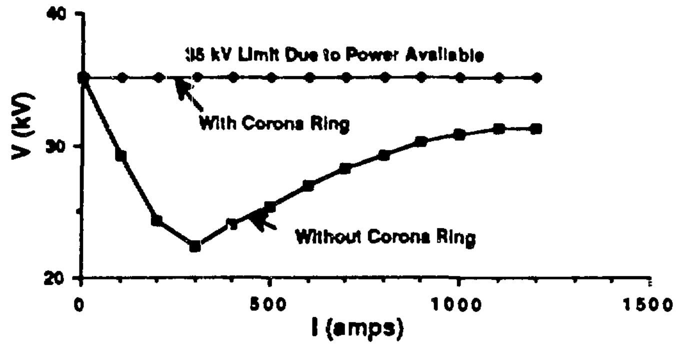

Fig. 2. Voltage standoff vs magnetic field current.

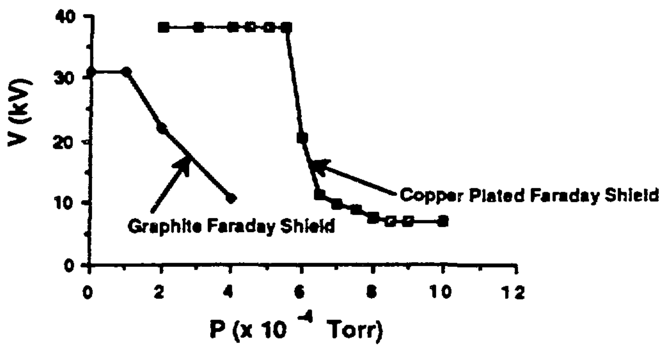

Fig. 3. RF voltage holdoff vs pressure.

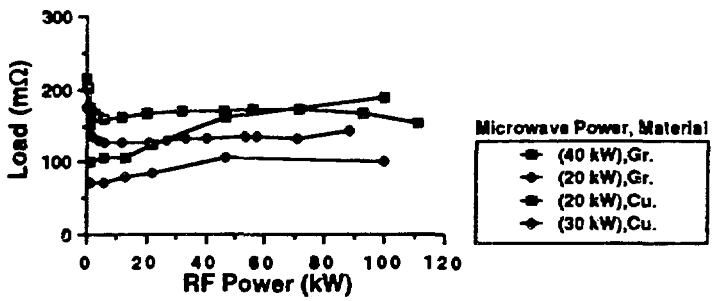

Fig. 4. Antenna load vs rf power as a function of microwave power and faraday shield material.