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THE OAK RIDGE RF TEST FACILITY*

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W. L. Gardner, D. J. Hoffman, H. C. McCurdy, T. J. McManamy, J. A. Moeller,† P. M. Ryan
Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, TN 37831

ABSTRACT

The RF Test Facility (RFTF) of Oak Ridge National Laboratory (ORNL) provides a national facility for the testing and evaluation of steady-state, high-power (~1.0-MW) ion cyclotron resonance heating (ICRH) systems and components. The facility consists of a vacuum vessel and two fully tested superconducting development magnets from the ELMO Bumpy Torus Proof-of-Principle (EBT-P) program. These are arranged as a simple mirror with a mirror ratio of 4.8. The axial centerline distance between magnet throat centers is 112 cm. The vacuum vessel cavity has a large port (74 by 163 cm) and a test volume adequate for testing prototypic launchers for Doublet III-D (DIII-D), Tore Supra, and the Tokamak Fusion Test Reactor (TFTR). Attached to the internal vessel walls are water-cooled panels for removing the injected rf power. The magnets are capable of generating a steady-state field of ~3 T on axis in the magnet throats. Steady-state plasmas are generated in the facility by cyclotron resonance breakdown using a dedicated 200-kW, 28-GHz gyrotron. Available rf sources cover a frequency range of 2 to 200 MHz at 1.5 kW and 3 to 18 MHz at 200 kW, with several sources at intermediate parameters. Available in July 1986 will be a >1.0-MW, cw source spanning 40 to 80 MHz.

Introduction

The ORNL RFTF provides the capability for testing full-scale rf antennas and components for such devices as DIII-D, Tore Supra, TFTR, and the Advanced Toroidal Facility (ATF). In addition to allowing more efficient use of confinement device operating time, the greater physical access and experimental availability made possible by a dedicated test facility provide the opportunity not only for a more careful assessment and diagnosis of rf system components, but also for the testing and evaluation of theoretical models of launcher/plasma interaction.

The key features of the facility are the presence of a steady-state plasma load and the availability of cw, high-power rf sources over a wide range of frequencies. The cw, high-power sources enable (1) testing of component power handling capabilities, thermal cycling fatigue, and suitability of materials, (2) assessment of cooling requirements and fabrication techniques, and (3) treatment of generic systems problems. The plasma environment is necessary to duplicate the low radiation resistance and time-varying voltage standing wave ratios (VSWR's) encountered on confinement experiments and for evaluating plasma effects on the antenna.

Facility Description

Figure 1 is an artist's cutaway perspective of the RFTF. The facility is a simple mirror configuration using the two superconducting development magnets from the EBT-P program. Given the constraints that these magnets place on facility design, trade-offs were made to optimize rf antenna access, diagnostic access, magnetic field strength, cooling of critical surfaces, and vacuum pumping. Note that a lead shield encloses the test area. This is required for

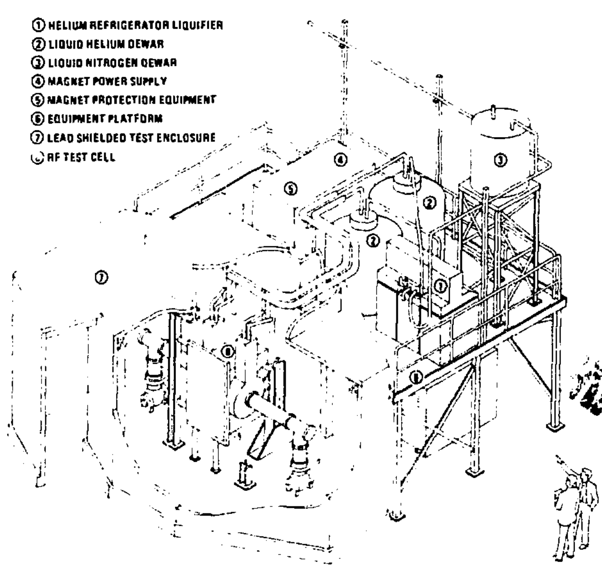

Fig. 1. Artist's cutaway perspective of the RF Test Facility.

safety, since large X-ray fluxes can be generated by electron rings formed under certain conditions of field, gas density, and electron cyclotron heating (ECH) power. Major subsystems are described below.

Vacuum Vessel and Associated Subsystems

Vacuum vessel design was influenced by the desire to maximize access, yet maintain reasonably high field strengths. Additional design considerations include the physical constraints of the magnets, power handling under full rf power loads, and protection of the vacuum system turbopumps from high magnetic fields. Figure 2 schematically shows the vacuum vessel sandwiched between the magnets with pumping extensions through the magnet throats to the vacuum system. Figure 3 is a photograph of this hardware. The vessel is fabricated from nonmagnetic stainless steel; the enclosed volume between magnets is roughly 1.5 m^3. The large (74 by 163 cm) rectangular opening on the front of the vessel is used for the insertion of experimental ICRH antennas. An additional 20 ports of various sizes on the other three exposed sides provide ample opportunity for diagnostic access; access through the ends of the pumping extensions is also available.

The vacuum pumping system consists of two 200-L/s Balzer turbopumps backed by a Roots-type blower/mechanical pump. Vacuum diagnostics and controls are based on standard ion and thermal convection gauges with logic interlocks controlling electropneumatic valves for system protection. The long vacuum extensions

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†Grumman Aerospace Corporation.

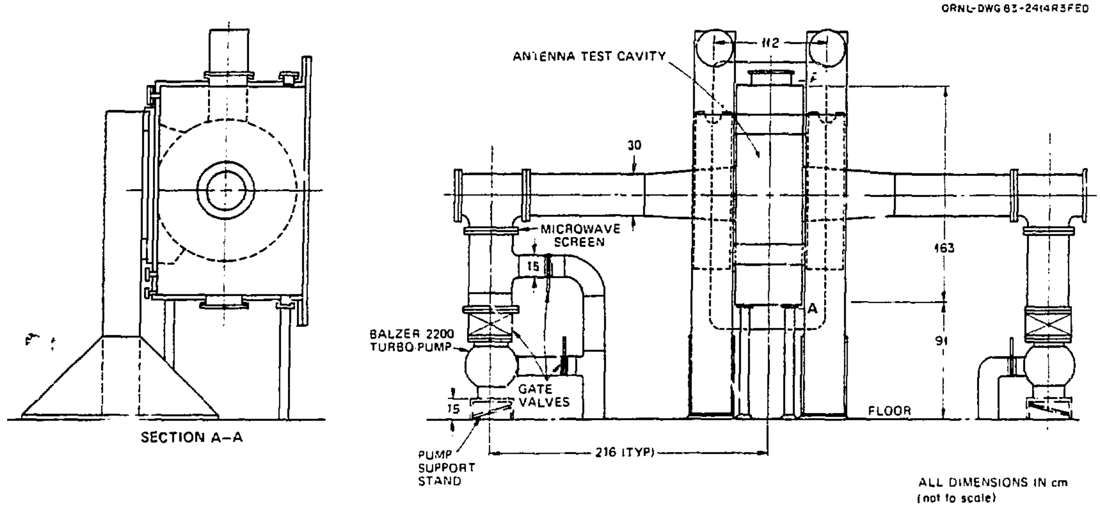

Fig. 2. Schematic of the antenna test area of the RF Test Facility.

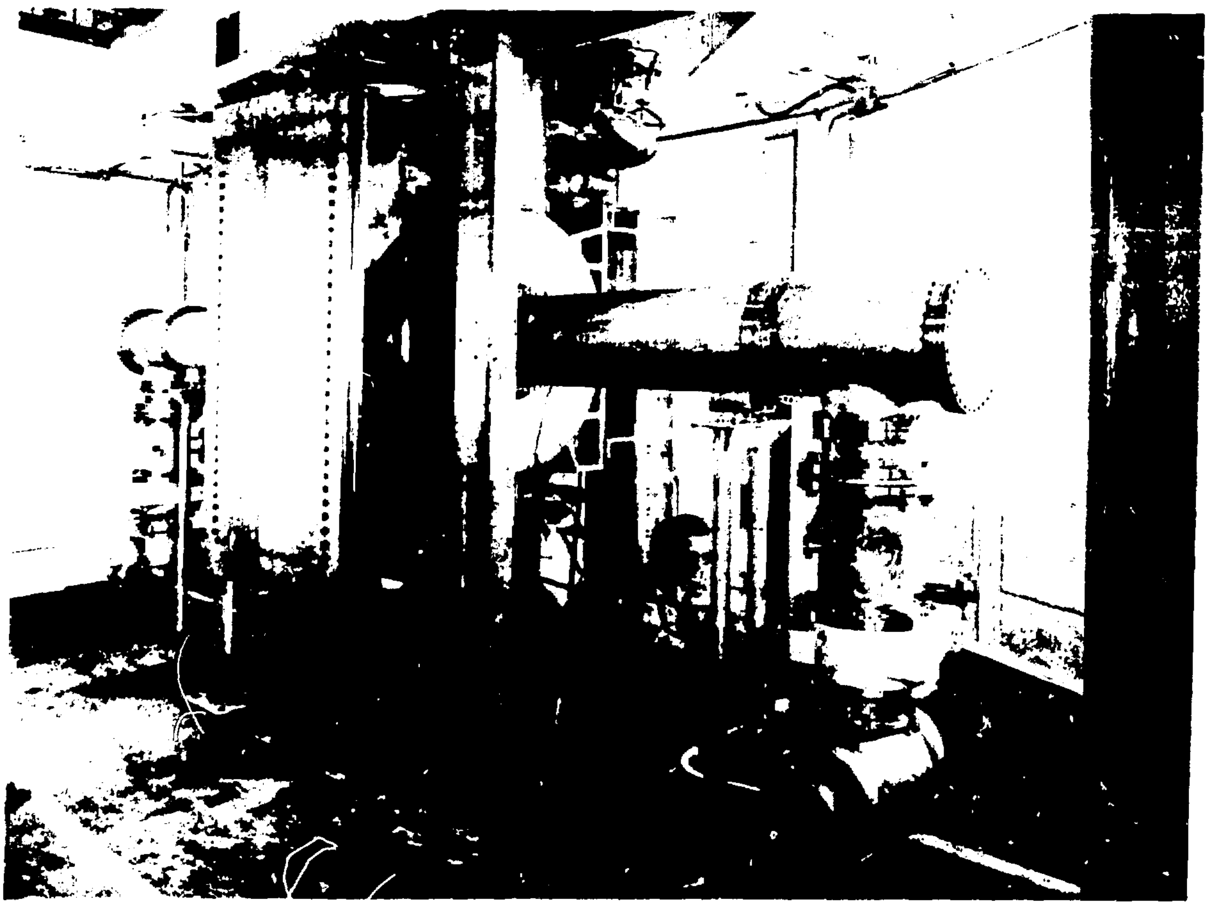

Fig. 3. Antenna test area hardware inside the lead enclosure.

place the turbopumps in a greatly reduced magnetic field region (110-G maximum); magnetic shields, good to 150 G, further protect the pumps. Microwave screens consisting of 0.125-in. stainless steel honeycomb, 0.25 in. thick and coated with copper, prevent the intrusion of microwave energy into the pumps with minimal reduction to throughput. Base pressure obtained by this system upon initial pumpdown was 1×10^{-7} torr.

A hydrogen gas injection system is used to provide controlled pressure for maintaining and adjusting plasma characteristics. Vessel pressure information is used to control a piezoelectric valve that adjusts hydrogen gas input to match output to the vacuum system.

Energy removal from the vessel is accomplished with a water-cooled liner attached to the vessel walls. Cooling is concentrated where field lines associated with resonant mod-B contours intersect the vessel walls. Figure 4 shows a representative mod-B resonance surface for 28-GHz, 1200-A operation along with associated field lines. The cooling liner extends through the magnet throats to the pumping tees. Cooling has been sized to handle the expected $\sim$15-W/cm^2 power density on the walls in the region of maximum plasma loss. This is based on 1 MW of cw power delivered to the plasma acting as an antenna load.

Magnet System

Depicted in Fig. 5 is a perspective of one of the two superconducting magnets used on RFTF. The operating maximum field is $\sim$3 T on axis in the magnet throats, corresponding to a coil current of 1200 A. Separation of the magnets, centerline to centerline, is 112 cm, providing a mirror ratio of 4.8. Figure 4 shows the calculated magnetic field geometry and mod-B contours under maximum field conditions.

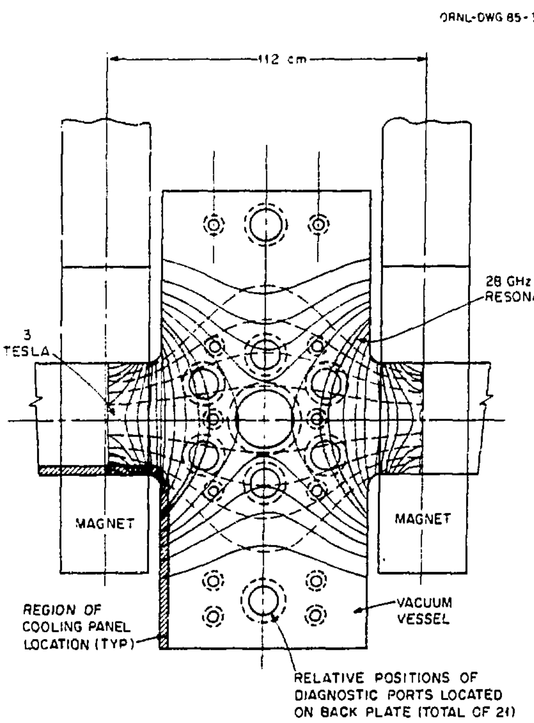

Fig. 4. The magnetic geometry of the facility magnets at maximum field strength. Also indicated are the mod-B resonance surfaces and cooling panel locations.

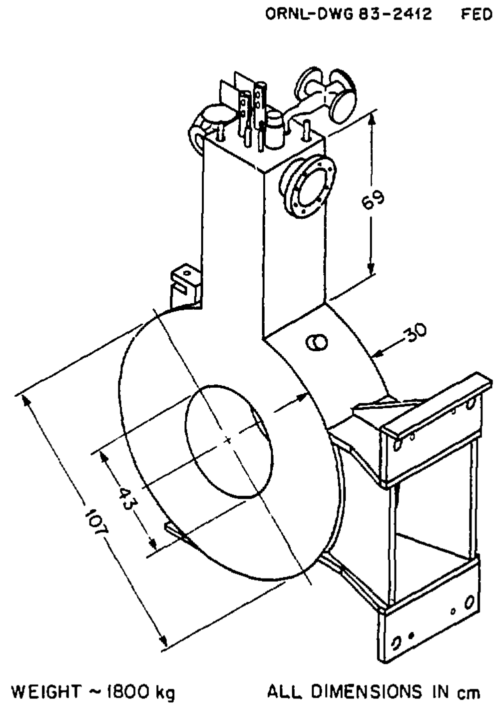

Fig. 5. Perspective of the RFTF magnet assembly.

A closed-loop cryogenic system using a model 1630 Koch refrigerator/liquefier (R/L) supplies liquid helium (LHe) to the magnets at a rate matched to their $\sim$15-L/h boiloff rate. The boiloff gas is subsequently recovered via a compressor, stored, and reliquefied. The closed-loop system piping is liquid nitrogen (LN_2) traced. Demand for LN_2 is supplied by a 15,000-L tanker through vacuum-jacketed transfer lines to a 500-L intermediate storage dewar and thence to the facility.

A power supply rated at $\pm$2000 A and $\pm$10 V with less than 1% ripple supplies current to the magnets connected in series. Across each magnet is a "dump" resistance of 0.24 Ω and electrically between the magnets is a "dump" breaker. Activation of the dump breaker by the magnet protection system interrupts the current from the supply and forces magnet current (stored energy) through the dump resistance, where it is dissipated. The magnet protection system acts whenever a quench (magnet windings going normal) is detected or whenever a manual dump command is given for safety reasons.

The magnets are supported on their own structures independent of the vacuum vessel and are designed to accommodate 1.5 times the expected attractive force of 165,000 kG.

Microwave System

Continuous plasmas with temperatures in the range of 1 to 10 eV and densities of the order of 10^{11} to 10^{12} cm^{-3} will be formed by electron cyclotron resonance breakdown using an existing 200-kW, 28-GHz gyrotron system. Microwave power is piped to the facility through evacuated, 2.5-in.-diam. waveguide and enters the vacuum vessel through a microwave-compatible vacuum valve. Evacuation of the waveguide was chosen to eliminate the need for a waveguide window at the vessel. Two small turbopumps teed from the waveguide are protected from microwave intrusion by a "sieve" with hole diameters less than a quarter-wavelength. Water flow calorimetry attached to the waveguide measures waveguide losses. Power accountability is achieved through accurate power balance measurements into a dummy load at the facility.

RF Sources

Existing high-power, cw rf sources available from related programs to support the first year's operations include:

Frequency range (MHz)	Power (kW)
2–200	1.5
2–30	100
3–18	200
30–60	50
40–80	50
175–215	50

Available in July 1986 will be a >1.0-MW, cw source spanning 40 to 80 MHz.

The rf power is fed through large-diameter coaxial cable, matching circuitry, and a 50-Ω vacuum feedthrough and thence to the facility for rf experiments.

Instrumentation and Diagnostics

Virtually all of the RFTF instrumentation is monitored by a programmable logic controller (PLC). System information is available to the operator through a series of display pages on a color monitor; each page corresponds to a major subsystem being monitored. System controls, for the most part, are separate from the PLC.

At this time a minimal diagnostics package is being implemented on the facility. Power loading on the vessel walls and rf components is measured by calorimetry consisting of ΔT transducers and flow meters on the water-cooling circuits. Plasma characteristics and profile are measured by a movable Langmuir probe. Additional plasma density information is obtained with a 4-mm microwave interferometer. Data acquisition is handled through CAMAC by a VAX-780. Additional diagnostics will be added as experimental and testing programs evolve.

Facility Status

Assembly and installation of facility hardware were completed in August 1985. Preoperational tests were successfully performed on the vessel and magnet vacuum systems in June 1985. The cryosystem was checked out in late July 1985, and the magnets were tested to full operating current (1200 A) in early August. Operation of the 28-GHz system is held up due to failure of a large power supply. Testing of the waveguide into a dummy load was performed using 20 kW of 10.6-GHz microwave power of which 14 kW was measured at the load. This system will be used to form first plasmas. Upon completion of diagnostic implementation and plasma characterization, the facility will be ready for antenna testing.