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Initial results from a Folded Waveguide ICRF Antenna development project

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Abstract. A folded waveguide (FWG) ICRF launcher has been built and preliminary high power tests completed. This project is intended to provide a proof-of-principle test, using a high density plasma load, of the high power density capability and other ITER-relevant advanced features of the FWG. The design is a 12 vane, 57 MHz unit with a quarter-wavelength resonator configuration. This FWG has a 0.31 m square cross section that can be installed with either fast wave or ion-Bernstein wave polarization and can also be retracted behind a vacuum isolation valve. A primary issue to be addressed by this project is the plasma loading and maximum power capability of the FWG. Initial high power tests on the ORNL Radio Frequency Test Facility have been conducted. Modeling of the FWG electromagnetic fields and calculations of loading have been performed as well as an investigation of alternate face plate designs that improve the coupling by allowing greater magnetic field penetration into the plasma. This FWG was originally designed for TFTR or PBX-M and is now being considered for the DIII-D tokamak at GA, the NSTX small aspect ratio device under construction at PPPL and the possible FSX experiment at PPPL.

INTRODUCTION

The folded waveguide is being investigated as an advanced ICRF launcher[1,2] that has a number of advantages over current strap antennas including: higher power density and power capability, all metal construction, internal matching, greater mechanical strength, lower electric fields near the plasma, more flexibility over launch spectrum and possibly greater plasma-antenna separation. Many of these features are particularly advantageous for ITER and reactor relevant plasma conditions. Although "record" high power operation of a FWG development unit has been demonstrated on the RF Test Facility at ORNL, many of these features have not been proven on a tokamak. Some key performance criteria to be determined are the plasma loading and the operational reliability. This project was originally undertaken to develop a FWG compatible with both the PBX-M and TFTR tokamaks at PPPL. The great flexibility offered by the small cross section makes this FWG quite compatible with a number of other tokamak experiments which are being investigated to further test the device.

DESCRIPTION OF THE FWG

The FWG design adopted is a 12-vane square cross section configuration with a quarter wavelength resonator. Some specifications are listed in Table 1. The cross section dimensions were originally designed to fit inside a port on the PBX-M device; however the small size is convenient for other devices such as DIII-D and NSTX. The frequency of 57 MHz is useful for a variety of experiments. To minimize the overall size and cost of the FWG, the quarter wavelength

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configuration was developed[1] that requires only half the length of the original half wavelength design and permits power to be fed through the rear wall. The design goal power capability of 4 MW would, if successful, permit operation at a power density of 5 kW/cm^2. Input power is fed through a 150 mm coaxial line and vacuum feedthrough located at the rear wall of the FWG. The coaxial center conductor connects to a coupling loop of adjustable area which permits changing the coupling to maintain an input match. Remote control of the coupling loop was not implemented in this design to save costs and minimize potential problems; however the addition of a remote control tuning is fairly straight forward.

Table 1 FWG specifications

Frequency of operation	56.9 MHz (measured)
Waveguide cutoff frequency	41.65 MHz
Outside dimensions	0.31 x 0.31 x 2.32m
Number of vanes	12
Unloaded resonant Q	550
Input match tuning range	7:1
Design power	2-4 MW(loading dependent)
Power density	2.5-5 kW/cm^2

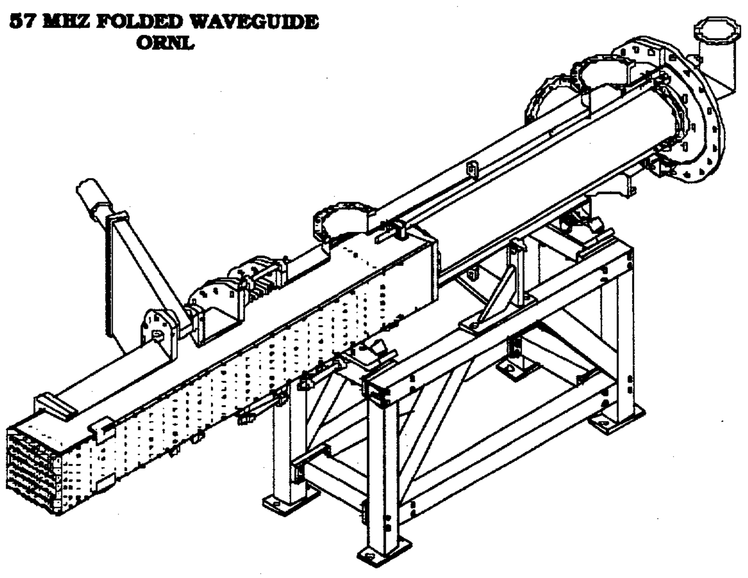

Figure 1. Exploded view of the FWG in the vacuum enclosure

The vacuum enclosure is designed to permit retraction of the FWG behind a gate valve for servicing, tuning, off-line conditioning and waveguide rotation without affecting the tokamak vacuum status. Motion of the FWG is accomplished with a re-entrant bellows around the feed coax. A radial motion of 1.3 m was required for the PBX-M tokamak and a slightly longer distance on TFTR (which was to use a different vacuum enclosure configuration). Details of the FWG and PBX–M enclosure configuration are visible in Figure 1.

MECHANICAL CONSTRUCTION DETAILS

A design goal for this FWG project was to develop a bolt-together assembly technology capable of being reconfigured and repaired, if necessary, while also providing reliable high-current joints to minimize arcing and maximize the cavity Q. Mechanical analysis of the disruption forces and stresses indicated that simple bolt-on vanes may fail due to concentrated stresses in the bolts and corners of the vanes. A tapered slot configuration was developed which results in mechanical strength essentially equivalent to a solid unit and high current-carrying capability.

Vanes and sidewalls were machined from stock sheets of stainless steel (6.35 and 16 mm thick respectively) that were sanded smooth. The slight warpage present in the sheet metal as received is straightened as the sidewalls are bolted together and the vanes pulled down into the grooves. The FWG face plate was machined from a block of stainless steel with a curvature of 1.75 m on the plasma side to provide a close match to the plasma edge radius. Equal poloidal and toroidal curvatures were used since only a very small mismatch results. This permits equivalent fast wave and ion Bernstein wave orientation of the FWG. The face plate is boron carbide coated using a commercial physical vapor deposition coating. The sidewalls and vanes were copper plated to approximately 75 μm thickness using specially built long plating tanks.

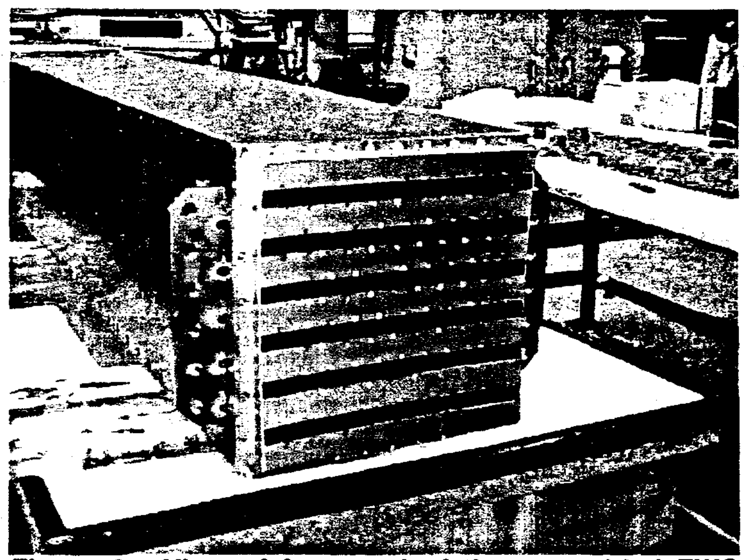

Figure 2. View of front end of the assembled FWG

Figure 2 shows the assembled FWG box from the front end, including mounting ears that were designed to adapt the FWG to the TFTR vacuum enclosure. Several thermocouples are attached to various spots and their leads brought out along the outside of the feed coax to the rear to eliminate possible snags as the FWG is inserted or retracted.

LOW POWER TESTS

A number of low power tests were conducted on the FWG. Parameters such as resonant frequency, matching adjustment range, cavity Q, magnetic field patterns, and loading effects were studied. Some measured values are listed in Table 1.

Figure 3a shows a toroidal scan of B_Z (the toroidal component) for two radial positions: 5 mm (light trace) and 50 mm (dark trace). The highly localized edge currents appear as spikes which decay rapidly away from the face plate as shown. Figure 3b shows a radial scan along the waveguide axis of B_Z with 0 mm corresponding to the face plate position (negative positions are inside the waveguide).

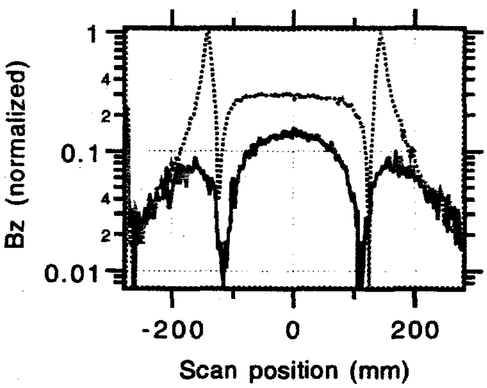

Figure 3a

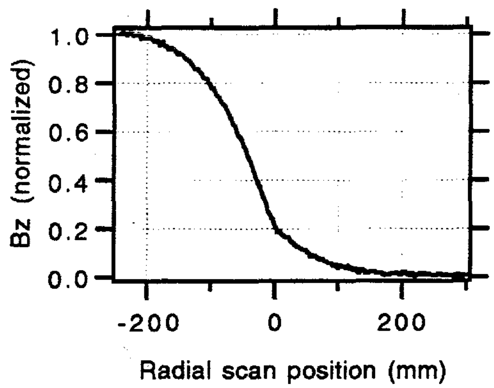

Figure 3b

HIGH POWER TESTS

Initial high power tests were performed on the FWG with the RF Test Facility at ORNL. These tests were discontinued early due to the scaled-back TFTR operation schedule. The results that were achieved are: the demonstration of RF bakeout of the FWG, the ease of multipactor conditioning for this device, and a power level of 100 kW for 100 ms pulse length. The only significant problems experienced during the short operation phase (approximately 1 week) were a few loose screws (which overheated) on the face plate and some particulate residue inside the FWG that may have been blown in from the bottom of the vacuum enclosure during vacuum pumpdown. The FWG is currently ready to resume high power tests.

IMPROVED FACE PLATE DESIGNS

To improve the coupling and further increase the power capability of the FWG, alternate face plate designs have been investigated. An improved version that uses interlaced wire loops to replace the shorting plate elements was studied on a low power mock-up FWG and found to provide approximately twice the coupling.

CONCLUSION

A high power, tokamak-ready development FWG was built and is essentially ready for testing on a tokamak. Work is under way to establish a new program on an operating tokamak for proof-of-principle tests.

ACKNOWLEDGMENTS

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1 Bigelow, T.S., *.et al.*, Conference on RF Power in Plasmas, Palm Springs, CA, 1995 (American Institute of Physics, New York, 1992) AIP Conf. Proc. **355,** 389-92 (1996)

2 Owens, T.L., IEEE Trans. Plasma Sci. **PS14,** 934-46 (1986)

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